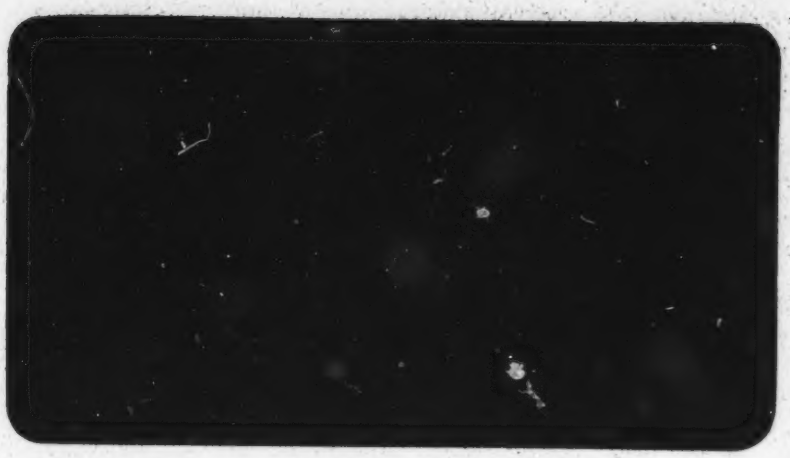

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Final Report

Prepared for the
Transportation Development Centre
Policy and Coordination Group
Transport Canada

Prepared by
Canadian Astronautics limited
1050 Morrison Drive
Ottawa, Ontario

March, 1989

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ENHANCEMENT OF THE MICROWAVE LANDING SYSTEM (MLS) SIGNAL ANALYZER

by

S. Radhakant, B. C. Blevis, Daniel Ho, Kamal Ali, M. Dillon

Canadian Astronautics Limited
1050 Morrison Drive
Ottawa, Ontario

for

Transportation Development Centre
Policy and Coordination Group
Transport Canada

March, 1989

"The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre."

Un sommaire en français de ce rapport est inclus avant la table des matières.

PROJECT TEAM

The project team for Canadian Astronautics Limited was composed of:

Dr. B. C. Blevis
Dr. S. Radhakant
Mr. Daniel Ho
Mr. Kamal Ali, and
Mr. Matthew Dillon.

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16. Abstract

This report describes work to further the development and to improve the accuracy and functionality of an MLS Signal Analyzer and Guidance Angle Simulator. The Signal Analyzer provides a first article test set that can be used for the comprehensive testing of MLS systems incorporating Azimuth, Elevation, Back Azimuth and High-Rate Azimuth antenna functions.

The work comprised two sets of tasks. The first included a set of hardware and software modifications designed to eliminate problems identified during the earlier field tests. The second comprised additional investigations, comprehensive system tests, and revisions to the Operator's and Software manuals. A number of changes were made to the software to create menus which were more user friendly, to provide more options for plotting, storing and retrieving data, and to detect any mistriggering.

The Signal Analyzer and the Guidance Angle Simulator were subjected to comprehensive system tests to characterize the temperature stability and performance of the equipment and to determine its accuracy. The equipment was determined to satisfy the approved test criteria, in most cases well within the limits specified. A number of recommendations are made in the report for further development.

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Centre de développement des transports
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16. Résumé

Ce rapport décrit le travail effectué par CAL pour compléter le développement et améliorer la précision et l'utilité d'un analyseur de signauxet simulateur d'angle de guidage pour les systèmes d'atterissage à hyperfréquence (MLS) développé auparavant pour Transports Canada.

Le programme comprenait un grand nombre de tâches divisées en deux categories. La première renfermait un ensemble de modifications du logiciel et de l'équipement pour l'élimination des problèmes identifiés pendant les tests opérationnels effectués auparavant. La deuxième renfermait des études additionnelles. Pendant la gamme de tests, plusieurs nouvelles anomalies avaient été identifiées et les études qui ont suivi ont fait l'objet d'une modification du contrat. Plusieurs modifications ont été apportées dans le logiciel afin de créer des menus commodes, visant à permettre plus de choix pour tracer, conserver et recupérer les données, et détecter les faux déclenchements.

L'analyseur de signaux et le simulateur d'angle de guidage furent soumis à des tests opérationnels compréhensifs afin de caractériser leur stabilité à la température, leur performances et de déterminer leur précision. L'équipement fut jugé satisfaisant aux critères des tests approuvés dans la plupart des cas, bien à l'intérieur des limites prescrites. Finalement, on préconise quelques recommandations pour un nouveau développement.

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EXECUTIVE SUMMARY

Microwave Landing Systems (MLS) will soon replace current Instrument Landing Systems (ILS) at the world's major airports. In order to ensure the continued safety and efficiency of airport operations, it is essential to develop methods and equipment to test, certify and commission MLS equipment. Based on the earlier development of a first article test set, Canadian Astronautics Limited (CAL) was contracted to complete the development and improve the accuracy and functionality of an MLS Signal Analyzer and Guidance Angle Simulator. The work was performed for the Transportation Development Centre of Transport Canada under DSS Contract number T8200-7-7530/01-SD, entitled "Completion of Development and Comprehensive Testing of a Microwave Landing System (MLS) Signal Analyzer". The Signal Analyzer provides a means for the comprehensive testing of MLS systems incorporating Azimuth, Elevation, Back Azimuth and High Rate Azimuth antenna functions and was designed primarily for use with an instrumented test range.

The Statement of Work provided originally comprised a large number of tasks which fell into two categories. The first included a set of hardware and software modifications designed to eliminate problems which had been identified during earlier field tests. These included such things as modification of the trigger circuitry to provide stable function triggering for the elevation system in the absence of an Out-of-Coverage Indicator (OCI) pulse, correction for the effects of phase centre offset and conical scan, and protection of data against power failure, as well as factory acceptance tests for the various tasks.

The second group of tasks comprised additional investigations considered to be desirable as a result of experience gained during an earlier contract. These included investigations of discrepancies in the azimuth angle, studies of the antenna turntable control, and temperature characterization of the Signal Analyzer.

During various tests, a number of additional anomalies were identified, in some cases apparently the result of commercial equipment supplied. Studies of the cause of these anomalies were the subject of an amendment to the contract. They included additional studies of options for turntable control, MLS receiver mistriggering, behaviour of a commercial signal generator, beam skewing at large angles and errors observed at negative elevation angles.

In addition to the work called up under the contract, CAL made a number of changes to the software to create menus which were more user friendly, to provide more options for plotting, storing and retrieving data, and to detect the occurrence of false triggers.

Comprehensive System Tests, including extensive field tests of the equipment using Transport Canada's test range at the David

Florida Laboratory, were carried out according to extensive test plans prepared by CAL and agreed by Transport Canada. The Signal Analyzer and Guidance Angle Simulator were determined to satisfy the test criteria, in most cases well within the test limits specified.

Based on the further experience gained and the results of the tests performed, a number of recommendations are made for the development of a second generation MLS Signal Analyzer.

SOMMAIRE

Les systèmes d'atterissage à hyperfréquences (MLS) remplaceront dans peu de temps les systèmes d'atterissage actuellement en place dans les principaux aéroports du monde. Pour assurer la sécurité et l'efficacité des opérations des aéroports, il faut développer les méthodes et équipements qui peuvent servir à mettre à l'épreuve, à certifier, et à mettre en service les MLS. Suite au développement antérieur d'un appareil d'essai, Transports Canada a engagé la compagnie CAL pour compléter le développement et améliorer la précision et l'utilité d'un Analyseur de signaux MLS et un simulateur des angles de guidage. Ces activités ont été effectuées au nom du Centre de développement des transports (CDT) de Transports Canada sous contract, MAS nr. T8200-7-7530/01-SD. L'analyseur de signaux permet de mettre à l'épreuve un système MLS dans son ensemble, y compris le fonctionnement des antennes du type azimut et élévation dans les modes élévation, azimut, azimut-arrière et azimut à grande vitesse. L'analyseur a été conçu pour être initialement utilisé avec un banc d'essai équipé pour les antennes MLS.

Le programme de travail original inclus un grand nombre de tâches qui ont été divisées en deux catégories. La première renferme un ensemble de modifications du logiciel et de l'équipement pour éliminer les problèmes identifiés pendant les tests opérationnels effectués auparavant. Ces changements sont notamment: modification du circuit à détente afin d'assurer un déclenchement plus stable pour le système d'élévation en l'absence d'une pulsation indiquant la limite de portée; rectification des effets d'un déplacement du centre de phase et des effets du mouvement conique du faisceau d'antenne; sauvegarde contre l'interruption de l'électricité; aussi bien que tests de qualification pour les diverses tâches.

Le deuxième groupe de tâches renferme des études supplémentaires qu'on estimait nécessaire par suite des expériences acquises pendant un premier contrat. Ces études ont inclus des examens des désaccords dans l'angle d'azimut, des études du contrôle de la plaque tournante de l'antenne, et la caractérisation de l'analyseur de signaux à la température.

Pendant la gamme de tests, plusieurs nouvelles anomalies ont été identifiées, quelquefois résultant de l'équipement commercial fourni par le Gouvernement. Les études de la cause de ces anomalies ont été l'objet d'une modification du contrat; elles comprenaient les examens d'autres possibilités du contrôle de la plaque tournante, le faux déclenchement du récepteur MLS, l'inclinaison du faisceau d'antenne aux grands angles, et les erreurs qu'on remarquait aux angles d'élévation négatifs.

En plus du travail demandé dans le contrat, CAL a apporté plusieurs modifications dans le logiciel afin de créer des menus commodes, en vue de permettre plus de choix pour tracer, conserver et recupérer les données, et pour détecter les faux déclenchements.

Les essais compréhensifs du système, y compris les tests opérationnels étendus de l'équipement, ont utilisé le champs d'antenne du laboratoire David Florida et ont été effectués selon un programme d'essais établi par CAL et avec lequel Transports Canada était d'accord. On a déterminé que l'analyseur de signaux et le simulateur de l'angle de guidage ont satisfait aux critères des tests, dans la plupart des cas bien à l'intérieur des limites prescrites.

Basé sur l'expérience additionnelle acquise pendant les travaux et d'aprés les résultats des tests, on préconise quelques recommandations pour le développement d'une deuxième génération d'analyseurs de signaux MLS.

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1. INTRODUCTION

The Microwave Landing System (MLS) has been chosen to replace the Instrument Landing System (ILS) which has been in use at the world's major airports for more than 40 years. It is expected that, within ten years, MLS equipment will be operational at a majority of Canada's airports, as well as at airports in the U.S. and in other parts of the world. The safety, and efficiency, of airport operations will depend on the reliability and accuracy of the installed MLS equipment. The ability to maintain the required accuracy will in the first instance depend upon the avionics, especially MLS receivers, on board the aircraft. However, the ultimate consideration in determining the accuracy and reliability of MLS systems will be the MLS transmitting systems installed at the ends of the runways.

2. OBJECTIVES OF THE PROJECT

Prior to the widespread introduction of Microwave Landing Systems, it is necessary to develop methods and equipment that can be used to test, certify and commission MLS transmitting equipment. Furthermore, test equipment is needed for in-service testing of the MLS transmitters. This project involved the development in Canada of a reliable and versatile test set that can be used for a first article test for any MLS Azimuth (AZ), Elevation (EL), Back Azimuth (BAZ) or High-Rate Azimuth (HAZ) antenna. In addition, the MLS Signal Analyzer (and the Guidance Angle Simulator) provided by Canadian Astronautics Limited (CAL) may be used to verify the operation of other MLS equipment and serve as a research tool. The major effort was to produce a test set that has the following features:

- o is an order of magnitude more accurate than commercially available receivers,
- o produces reliable and repeatable results,
- o provides Transport Canada with the means for recording actual video output of the transmitters, and
- o permits Transport Canada to investigate the accuracy of angle measurements provided by MLS transmitters.

The MLS Signal Analyzer produced under an earlier contract by Canadian Astronautics Limited (CAL) was not sufficiently accurate to be used with confidence as a test set for commissioning MLS equipment. Furthermore a number of anomalies were observed which required further investigation. The present contract was directed primarily to improving the accuracy and functionality of the earlier system, as well as gaining a better understanding of all possible system errors.

3. METHODOLOGY

The work which was performed under the present contract

consisted of improvements to the existing Signal Analyzer and of tests of its performance and capability. Some of the modifications required were not clearly understood or specified at the start of the contract. The methodology adopted to overcome this was for CAL to study the various problems, suggest methods for improvement or testing, to have these reviewed and approved by Transport Canada, and then to proceed with the modifications. In one case, the conical scan and phase centre offset corrections, Transport Canada supplied the formulae to be implemented in software. The formulae were derived by Transport Canada with some input and review by CAL. A number of review meetings were scheduled to ensure that the highest priority items were tackled in a manner acceptable to Transport Canada. Its approval of proposed plans was essential before work could continue on the modifications.

A milestone strategy was adopted to ensure that work proceeded on schedule and within budget, to the extent possible in this project. There were inevitable delays due to the proposal and approval stages before major tasks were initiated and, in many cases, problems were encountered, either with the Signal Analyzer or Government Furnished Equipment (GFE), which could not have been anticipated.

4. TASKS TO BE PERFORMED

The tasks to be performed by CAL under the present contract were defined in the Statement of Work. The Statement of Work comprised 15 Tasks divided into two parts. The first part consisted of a set of hardware and software modifications to the earlier system designed to eliminate the problems identified during earlier field tests at Transport Canada's test facility at the David Florida Laboratory (DFL) of the Department of Communications. The tasks included factory acceptance testing of the various modifications. The second set of tasks included additional investigations that were considered desirable as a result of earlier experience. However, the second set also included comprehensive system tests, revisions to the operator's and software manuals, and the final report.

Under an amendment to the contract, a number of supplementary investigations were also undertaken. These included studies of the test range turntable control, mistriggering of the Bendix receiver, behaviour of the IFR generator, beam skewing at large angles and errors observed at negative elevation angles. The results of these studies are presented in Section 5.5.

PART I

4.1 Elevation Frame Timing

When the Signal Analyzer was tested at DFL using the MLS transmitter, it was observed that the elevation frames jittered considerably, making it impossible to obtain consistent elevation scans, and therefore, guidance angles. This did not occur for

any of the other functions, which could be tested using either an MLS antenna or a test signal generator. Study of this phenomenon indicated that the problem was due to the fact that the elevation frame did not have an Out-of-Coverage Indicator (OCI) pulse. The original design of the trigger circuit assumed that an OCI pulse would be present. However, this is an option for both Azimuth and Elevation functions, and the trigger circuit needs to be stable whether or not OCI is present.

The task was to modify the trigger circuitry to provide stable function triggering in the absence of an OCI pulse for both the elevation and azimuth systems. A breadboard modification was to be made and field-tested using the elevation antenna. Once the modifications were proven to be adequate, CAL was to redesign the board layout for the digitizer. This redesign was to include improved signal isolation and better analog and digital grounding, and to eliminate jumpers which had been found necessary in the old board. A new printed circuit board functionally similar to the old one was to be made and tested. The revised trigger circuit was to allow the complete guidance angle to be processed, including the complete preamble.

4.2 Phase Centre and Conical Error Compensation

The algorithm used for computing the guidance angle was found to have been based on wrong assumptions. It had been assumed that the antenna pattern for a horizontally scanning beam would be independent of the scanning angle. This, however, is not true for beams that are electronically steered, as in the MLS. The actual scanning beam is conical. Thus, the guidance angle depends on both the approach azimuth angle and elevation. The task for CAL was to develop the correction for the conical scan and for the phase centre offsets in cooperation with Transport Canada, to modify the necessary modules to include the corrections, and to include additional menu options to allow the operator to input the necessary parameters. These parameters would include at least the three-dimensional position of the phase centre, and the position of the receiver relative to the phase centre.

The modifications were to be done in such a way as to allow the future addition of different compensation procedures.

4.3 Elevation Scan Reversal

Because of the manner in which the elevation antenna is mounted at DFL, on its side so that the scan is horizontal rather than vertical, there are two possible orientations of the antenna. The Hazeltine antenna can be mounted only on one side. This resulted in the computed elevation angle having the wrong sign. It was necessary to modify the software so that the sign of the angle can be selected by the operator. This will permit the Signal Analyzer to be used for general applications where either orientation may be required.

4.4 Midscan Error Value

The midscan error as calculated from the original software code had been found to be twice the actual error. This was to be corrected.

4.5 Frame Recordings

The unmodified Signal Analyzer did not record 16 consecutive frames of any scan. Instead, it recorded 16 milliseconds worth of data for every function. Thus, for the elevation function, which is 6 milliseconds long and sometimes separated by only 2 milliseconds, it was possible to record more than a single frame each time. This problem became apparent only when the real elevation sequence was tested. Under the present contract, CAL was to study this problem and recommend a solution to Transport Canada for approval. The solution was then to be implemented, tapes and plots made of the recorded data, and these were to be provided to Transport Canada for verification. This was to be done for all the functions.

4.6 Power Fail Restart

It had been found during earlier tests at DFL that, although the system normally started up well after a power failure, the data which had been collected previously were lost. Occasionally, the system would not start up at all. CAL was tasked with finding the reason for this behaviour, and implementing a suitable solution.

4.7 Invert GANS Waveform

The waveform sent to the upconverter by the Guidance Angle Simulator (GANS) is inverted. This is passed through a logarithmic amplifier which again inverts the signal before presenting it for upconversion to the MLS frequency. When this is recorded on tape, the log video is not inverted. Transport Canada discovered that, in order to play the log video back through the GANS, they had to do a considerable amount of preprocessing on the log video. This was both time consuming and difficult. It was CAL's task to invert the tape data as required by the GANS, so that the preprocessing could be avoided.

4.8 Angle Printout

The angle printout in the earlier version was not clear. The zero offsets for the encoder and turntable were not corrected before the printout, whereas the angle error was. This was to be rectified. At the same time, CAL was to ensure that the values recorded on tape were also consistent with the printout.

4.9 Menu Titles

It was found that the menus presented to the operator were sometimes difficult to follow. It was suggested that menu titles be displayed in order to simplify operation.

4.10 Plot Titles

The titles printed on the plots were to be the same as the header entered by the operator. However, the plot titles were restricted to 40 characters, while the headers were not. As a result, sometimes only part of the header appeared, leading to confusion. This was to be set right.

4.11 Factory Acceptance Tests

Factory Acceptance Tests for the above tasks were to be conducted on the basis of a pre-approved test plan. This would complete the first part of the modifications.

PART II

The remaining tasks were of a more investigative nature. Anomalies observed, both in the factory and at DFL were to be studied, and solutions were to be recommended.

4.12 Temperature Stability

The earlier version of the Signal Analyzer exhibited some unusual temperature dependence, the causes of which were undetermined. The task presented to CAL was to redo all the temperature testing, thereby characterizing the behaviour of the Signal Analyzer at different temperatures. The major concern was the accuracy of the guidance angle measurement.

4.13 Azimuth Anomalies

The Azimuth antenna was extensively tested at DFL in March of 1986. It was observed by Transport Canada that the angle measured was occasionally totally wrong. The reason for this was not apparent. CAL was asked to observe the testing of the modified Signal Analyzer at DFL, for a period of about 5 days, and to determine if the anomalies still occurred. If they did, CAL was to study the phenomenon and recommend a suitable solution.

4.14 Comprehensive System Tests

CAL was expected to perform comprehensive tests on the Signal Analyzer to verify its functionality. In order to do this, CAL was to first provide Transport Canada with the complete test plans. When these were approved, CAL was to perform the tests that could be done in the laboratory. If the results of these tests were encouraging, CAL was to proceed with the tests at DFL. Transport Canada was to be responsible for ensuring that the DFL facilities were available and functional when the field tests were to be held. The major thrust of the comprehensive tests was to prove the accuracy of the Signal Analyzer, and to collect data on tape for Transport Canada to analyze.

4.15 Additional Investigations

Additional investigations were planned. The first of these was to study the interface to the Scientific Atlanta 2012A turntable controller, to find better and faster ways of accurately pointing the antenna in the right direction. Another task was to investigate the possibility of speeding up the recording of log video data on tape. A third task required the monitoring of the serial line used by the IEEE Extender to connect the Signal Analyzer to the SA2012A Controller. This had been shown to be error prone during earlier field tests.

The recommendations for the first of these tasks are presented in Section 5.5.1 below. It was found that the tape recording could not be speeded up. This was a limitation of the tape subsystem and the device driver, and could not be improved. The serial line referred to earlier was ultimately replaced by DFL, making the last task redundant.

5. ACCOMPLISHMENTS

5.1 Hardware Modifications

CAL's first hardware task was to improve the trigger stability for the elevation frames. As stated earlier, this was found to be a problem only for the Hazeltine Elevation antenna, which does not supply an OCI pulse, the OCI pulse being optional for MLS antennas. The original hardware design was based on the assumption that there would be one. The circuitry was modified using the old digitizer board. The modification involved changing a counter. This counter originally counted to 16, and encountered problems if there were no pulses after the DPSK. The counter was modified to trigger after the twelfth bit is recognized, if the twelve bits (as indicated by the DPSK) agreed with the antenna function code desired. The modification made was tested on the MLS Elevation antenna at the Transport Canada laboratory. It was observed that the triggers were steady, and that the problem had been corrected. Transport Canada then allowed CAL to proceed with a new layout of the digitizer board, incorporating the changes that had been tested.

At the same time, using the old layout as a starting point, more ground plane area was added for the analog portion of the board and it was verified that the digital and analog grounds were properly isolated. The reason for doing this was to reduce any noise on the signal lines. It had been suspected that some of the anomalous readings obtained earlier were due to noise and interference problems. No changes were made to the circuitry other than the one mentioned earlier. The printing of the new circuit board was entrusted to the same company as was used earlier, to avoid having to redraw the schematics. The board was populated and tested at CAL, to ensure that it was functionally equivalent to the previous digitizer board.

When the board was incorporated into the system, it was found that spikes showed up occasionally in the digitized output from the signal analyzer. The problem was noticed when occasional large errors were observed in the guidance angle computation, and sometimes when plots were made of all sixteen frames. As a result, additions were made to the software which permitted the operator to identify scans in which spikes were observed and to plot only those frames where large errors were observed.

The cause of the spikes was traced to a timing problem on the board, which was easily corrected by changing a time constant. The Signal Analyzer was then run for a number of cases, in order to observe the spikes. No spikes were, or have since been, observed in any of the testing. It is believed that the spikes may have been responsible for the azimuth anomalies observed earlier. Occasionally, the computed guidance angle would be totally wrong. If spikes occurred, they could be wrongly picked out as the TO or FRO beams, thus giving totally wrong guidance angles. Such azimuth anomalies have not been observed with the new digitizer hardware.

5.2 Software Modifications

Both Transport Canada and CAL studied the corrections that needed to be made for the conical scan, and the displacement of the antenna phase centre. A consensus was reached on the corrections to be applied, and on the data that needed to be incorporated into the routine that made the corrections. CAL then coded a new module "ANGLE", which applied the Conical scan Correction, as well as the correction for the phase centre offsets. The new module was coded in such a way that Transport Canada can later easily modify the corrections if necessary. All the parameters that need to be entered by the operator were included as queries in the operator interface. This ensured that they could be changed without editing the program. The queries for these parameters were organized in a block, that could be left untouched. It is thus not necessary for the operator to enter these values for each session. The parameters may be entered into the file "QUERY.ML" as default values. The new module "ANGLE" was tested extensively, using the Transport Canada computations of the corrections to check the results. Agreement between the two independent calculations was extremely good. The routine "ANGLE" was frozen once the results agreed.

Modifications were made to the routine "SIGPROC" to include the scan reversal for the BAZ function, as well as for the Hazeltine Elevation antenna. A query was also added to the operator interface to allow the operator to choose this option. The additional factor of 2 in the computation of the midscan error in this routine was also removed. While making these modifications, a number of other small errors were discovered and corrected. For example, in one case the last line of a block of code that was supposed to be commented out was not commented out. This caused unpredictable results. When this was corrected, it

was found that earlier unexplained system crashes disappeared. Other changes were of lesser importance.

Earlier, it had been observed that, occasionally, two elevation frames were recorded as part of one frame. The reason for this was not immediately understood. This problem was found to be due to the fact that 16 milliseconds worth of data was recorded per frame, no matter which function was being exercised. This was not detected during factory tests, since almost all tests were done with the GANS as the signal source. The GANS outputs elevation frames at a constant rate of 39 Hz. Hence, two elevation frames would never occur in a 16 millisecond data collection interval. At the DFL facility, however, the elevation frames occurred at the true MLS timings, thus revealing a problem. The correction for this could be made only after the new digitizer board was ready. The jitter in the elevation frames was removed first. Once this was accomplished, the software module "SIGNAL" was modified to record only the correct frame length for each function regardless of the function. This correction is equally relevant to the HAZ and BAZ frames which are shorter than 16 milliseconds.

In attempting to debug and verify the modifications for frame recordings, it was observed that there was no easy method to produce plots when errors were suspected. CAL, on its own initiative, decided to put in an option to plot the log video. This was done by letting the operator choose a plot output option. If this is enabled, the operator can ask for any set of consecutive frames to be plotted. This has proven to be a useful debugging tool, and has been incorporated into the system as a permanent feature. It proved to be particularly useful in detecting the occurrence of spikes referred to earlier.

Another deficiency in the Signal Analyzer was the fact that 16 consecutive frames could not be recorded by the system. Careful review of the code revealed that the overhead between frames was very high. Part of this is unavoidable in this system because it is due to the overhead in the VersaDos. However, there was a piece of code required to organize the collected data bits into the right order, to produce the 12 bit digitized levels. This piece of code, in a module named "COLLECT" was executed originally after each frame was collected. The module "COLLECT" was removed from the time critical portion of the code, and executed only after all 16 frames were collected. This speeded up the data collection considerably. However, the problem of proving that 16 consecutive frames were recorded still remained. After discussions with Transport Canada, it was agreed that a time tag would be added to each frame, inserted just after the frame was collected, and in units of 10 milliseconds, which is the time unit used by the operating system. Using these time tags, it is possible to estimate the time taken for 16 frames. This may then be compared with the MLS timings for the function chosen. When this was done, it was observed that the Signal Analyzer does acquire 16 consecutive frames virtually all of the time.

One rather annoying feature of the Signal Analyzer had been its response to improper program termination or power failure. It was observed that, if the Signal Analyzer program was aborted, the system would not restart properly the next time. Part of the problem was traced to the way the operating system uses the driver for the OPIO (DMA) board. When the driver is first used, a channel is opened for the OPIO. This channel is closed when the program is properly terminated. If the program is not properly terminated, the channel cannot be closed, or reassigned. The only way out is to reboot the system. This is not a problem in the case of power failure, because the system has to be rebooted anyway. To avoid improper program termination, a warning is issued to the operator not to hit the BREAK key during critical periods.

If power failure occurred, two possible problems arose. The first problem arose if the file STATUS.ML was actively being used when power failed. In that case, the file was wiped out. When the program was next run, it would stop because the file was not present. To overcome this problem, the program was modified to maintain an extra copy of the file, and only one of these is active at any time. This way, if one is lost, the other can be used.

A more serious problem was the loss of data on power failure. This was overcome by correcting the code to use the old data if a power fail occurred, but to start fresh otherwise. The problems relating to power fail restart were thus solved. The changes made to the modules have been tested and verified.

The next major accomplishment was to invert the GANS waveform. With the previous version of the Signal Analyzer, Transport Canada found it very difficult to play back data that had been recorded on tape. The software modules controlling the playback were modified to invert the GANS waveform, and also to add the DPSK bits that are not recorded on tape. The tape handling routine was also modified by CAL in order to make it easy for Transport Canada to locate frames on the tape in order to play them back into the GANS.

The printout provided earlier was confusing. These were modified to print out the angles after all the zero-offsets are removed, so that angles can be compared easily. The formats for a number of variables were changed to reflect the accuracy of the data. for instance, log video levels are printed to 1 decimal place in dB, rather than to three decimal places. Other useful information, like the phase centre offset correction and the conical scan correction were added to the printout.

Menus presented to the operator have been made clearer, by naming each menu, and by expanding and clarifying the queries asked, so that the operator does not have to refer to a manual to understand the menus. A "quit" feature has been incorporated, to make it easy for the operator to go to the higher level menu. Furthermore, exiting accidentally from the program has been made difficult.

Because the plot titles were limited to 40 characters, they were not always the same as those on the printout or tape which could extend to 80 characters. This has been rectified by restricting the operator entry (of the header) to 40 characters.

When all these modifications were complete, a factory Acceptance test plan was prepared. This was approved by Transport Canada. The tests were conducted, and the milestone was signed off when Transport Canada was convinced that all the modifications were correct.

The next major accomplishment was performing the temperature stability measurements. First, a plan for temperature testing was presented to Transport Canada. When this was approved, the temperature stability measurements were performed. It was found that the Signal Analyzer behaved well at low temperatures (10°C), but at 40°C the system showed a number of anomalies. A large number of computed angles were not correct, and the cause of the problem was not obvious. On the second day of testing, the plotter was added to the system, and plots of log video were obtained. Only then did it become apparent that, at the higher temperatures, a number of frames were displaced in time, and that the system was mistriggering. Further temperature measurements were abandoned till the problem could be further investigated. Subsequently, it was shown that the Bendix MLS receiver generated correct DPSK data even on noise. This occurred only at the higher temperatures. When this happened, the Signal Analyzer started collecting data at the wrong times, thus confusing the software. Moreover, the software did not re-initialize variables properly when this happened, and unpredictable results were obtained. The software was modified to do all the necessary parameter initialization, and also to detect when frames were mistriggered. This was achieved by setting a threshold for the DPSK level, above which frames were considered to be valid. If the DPSK level was below the threshold, the frame was rejected as being mistriggered. When the temperature stability measurements were repeated after these modifications were made, no anomalies were observed.

In order to study the effects of temperature on the accuracy of measurement, the Signal Analyzer was placed in a temperature chamber. Measurements of the guidance angle were made using the GANS as source, at various temperatures. The temperature in the chamber was varied from 10°C to 40°C, in steps of 5°, starting at the low temperature, proceeding to 40°C and back down to 10°C. This was done to see if the measurements depended on whether the temperature was rising or falling. It was observed that the guidance angle was correct to within 0.004° at all the temperatures. The DPSK level, measured with a spectrum analyzer, did vary with temperature. The results of the power measurements are shown in Table 1 below.

Table 1 Power Measured as a Function of Temperature

Temperature (°C)	DPSK Level (dBm)
10	-18.0
15	-18.4
20	-18.6
25	-19.0
30	-19.2
35	-19.6
40	-20.0
35	-19.5
30	-19.2
25	-19.0
20	-18.8
15	-18.4
10	-18.2

It is clear from the above table that, to within the measurement accuracy of 0.2 dBm, there is no hysteresis in the power. However, there is a variation of 2 dBm in the power over a 30°C range in temperature.

5.3 GUIDANCE ANGLE ACCURACY

A significant task to be performed by CAL was to prove the accuracy of the Signal Analyzer. In order to do this, it is necessary to analyze all sources of error, and devise a means of measuring these contributions to the total system error. A block diagram of the MLS Signal Analyzer unit is shown in Figure 1 below.

If the source of the MLS signal is the IFR Signal Generator, the signal passes through both the receiver and the digitizer, and is finally stored in the MLS processor unit for further processing. When the MLS signal is generated by the Signal Analyzer's internal GANS, which uses a Taylor-weighted distribution function, the signal passes, in addition, through the D/A converter and upconverter units.

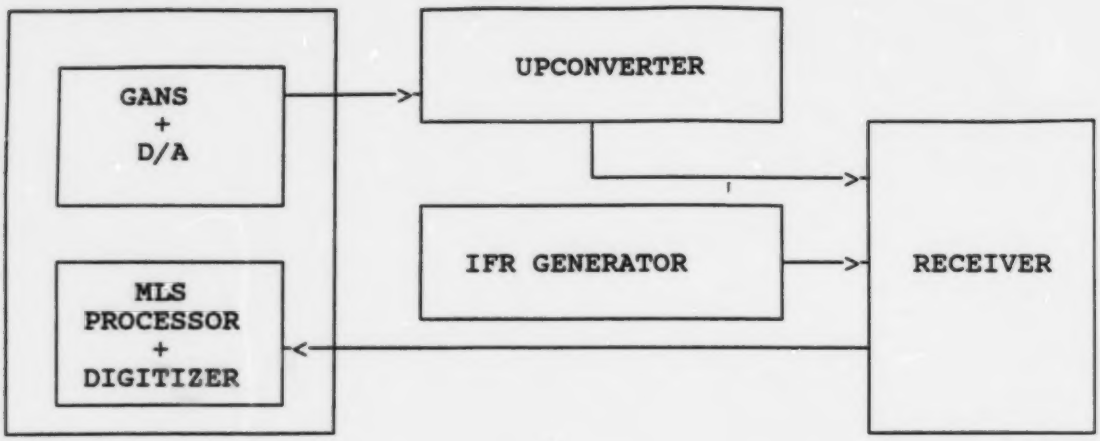

Figure 1 - System Block Diagram

The accuracy in guidance angle measurement achieved by the Signal Analyzer depends on a number of factors. These include:

a) The "correctness" of the data file and the algorithm used.

CAL supplied a tape of the data recorded during the Guidance Angle Accuracy test. These data were independently examined by Transport Canada to verify that the recorded data showed no abnormalities. The algorithm used consists of finding the beam centres for the TO and FRO beams at levels with respect to the peak of -1dB, -2dB .. -10dB. The -3dB centres are then found by linear interpolation of the observed values. The time difference between the -3dB centres is proportional to the guidance angle (apart from phase-centre offset and conical angle corrections). The raw angle from a single frame gives us a probable error of 2 microseconds (the resolution of the measurement). This corresponds to an angle of 0.04°. The use of 10 points to obtain the -3 dB beam-centre introduces an improvement of at least $\sqrt{10}$ in the guidance angle accuracy. Sixteen frames are used to obtain a single guidance angle, thus improving the accuracy by another factor of 4. Therefore the expected error in guidance angle measurement is $(0.04/\sqrt{10})/4 \approx 0.003°$.

b) Signal level distortions introduced by non-linearities in the D/A converter.

Non-linearities in the D/A converter will affect the shape of the GANS signal. The maximum non-linearity in the D/A converter used in the GANS is ±1 least significant bit (LSB), which corresponds to approximately 0.012 dB. The

Taylor weighted beam has a slope of 0.15 degree/dB at the -3 dB point, which would give rise to an angle error of less than 0.002°. Taking the same error for both the TO and FRO beams, there is a possible pointing error of 0.004° in the beam generated by the GANS for a single frame. Averaging over 16 frames, this amounts to an error of 0.001°.

c) Timing errors introduced by the D/A clock.

Errors due to timing or jitter in the D/A clock can also introduce errors in the generated beam. Using the value of 0.15 degree/dB as the gain slope, the allowable tolerance in the jitter can be calculated. An error of one-half a resolution cell (or 0.006 dB) is equivalent to a jitter of 0.006*0.15*50 microseconds. Since 1° corresponds to 50 microseconds, this gives rise to an allowable jitter of approximately 45 nanoseconds. The Fox F1100 crystals used to generate the timing signals for the D/A process have short-term stabilities of the order of a few picoseconds. This is orders of magnitude better than required. Hence, no significant error is introduced by the jitter of the D/A clock.

d) The linearity of the RF modulation process.

Non-linearities in the RF modulation process affect the accuracy of the beam generated by the GANS. A detailed discussion of the effects of non-linearities is given below, in f). The analysis used there applies to all non-linearities present in the system.

e) Random or asynchronous noise introduced by the receiver.

It is possible that the receiver can superimpose an asynchronous noise on top of the log video. CAL measured this noise, and found that there is a component of this noise at a frequency of 25 kHz. However, the magnitude of this noise component was extremely small, amounting to only 60dB. This is shown in Figure 2.

The statistical analysis described later in this section is designed to relate to the effects on the guidance angle accuracy of all random errors that occur in the system.

f) Non-linearities in the receiver.

These non-linearities could affect the angles measured, using either the GANS or the IFR. The effects depend on the shapes of the TO and FRO beams, as well as on the nature of the non-linearities. The receiver non-linearity could be different for increasing signals and decreasing signals, causing a change in the shape of the beams. It is assumed that this is the case. If we first consider small guidance angles near boresight, we can assume that the TO and FRO beam shapes are identical, and that the beams are not

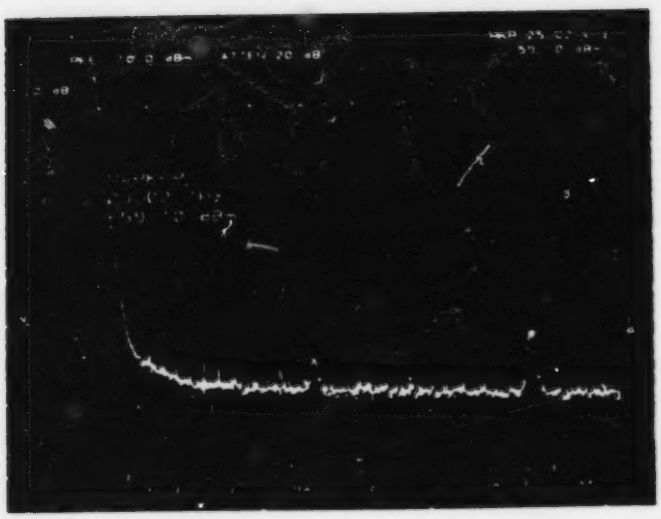

Figure 2. Asynchronous Noise from the Receiver

skewed. If this is the case, non-linearities in the receiver will distort both the TO and FRO beams identically. Hence, the -3dB centres would be separated by the same time, as if there were no distortion, and the error introduced in the angle measurement will be zero. However, the midpoint of the scan could be shifted, causing an error in the asymmetry.

For the case of large guidance angles, far from boresight, the TO and FRO beams will be skewed. This means that, if the non-linearity of the receiver shifts the -3dB point of the TO beam centre by a certain amount in time, the -3dB point the FRO beam centre would shift in the opposite direction, as shown in Figure 3 below. This shift in the -3dB beam centres causes an error in the angle as seen by the Signal Analyzer.

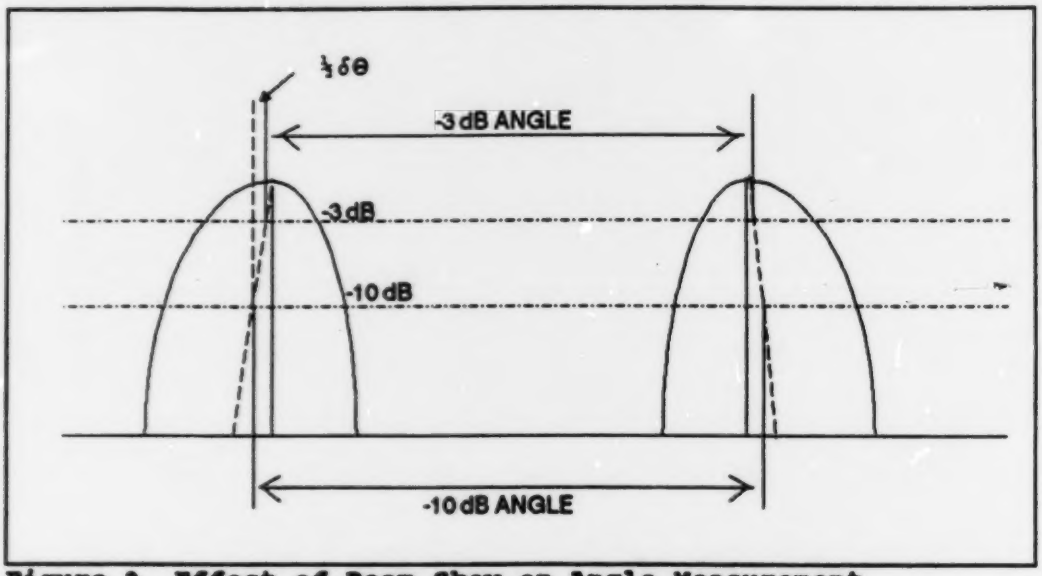

Figure 3 Effect of Beam Skew on Angle Measurement

Let us represent the error by $\delta\theta$. This error is proportional to the skew of the beam. The skew can be represented by the tilt of the beam away from the vertical. This is the slope of the beam-centres expressed in degree/dB. The error $\delta\theta$ is given by

$$\delta\theta = \delta p * m$$

where δp is the error in estimating the -3dB beam-centre, and m is the slope of the beam-centre line in degree/dB. It is easy to see that δp is determined by the non-linearity in the receiver, particularly if the signal saturates the receiver. It is therefore extremely important to ensure that saturation does not occur. The tilt m is expected to vary with guidance angle, increasing as the angle moves away from boresight. It will contribute most to the angle error

at large guidance angles. A fairly pessimistic estimate of m is one-half the slope of the beam at the -3dB point which is of the order of 0.15 degree/dB. Thus, m can be estimated to be 0.08 degree/dB. A very pessimistic value for δp is 1%, due to a 1% error in estimating the peak of the beam. At the -3dB point, this error is estimated to be 0.03 dB. Using these, we get

$$\delta\theta = (0.03*0.08) \approx 0.0024^\circ$$

It is emphasized that this is an over-estimate of the error.

However, there is another source of error that has so far not been considered. This arises from the fact that the guidance angle has been arbitrarily defined by ICAO to be measured at the -3dB level. The level at which it is defined is inconsequential, provided the beams are not skewed. If, however, they are, as is the case far from boresight, the errors could be large. If, as before, the tilt or skew is pessimistically estimated to be 0.07 degree/dB, the separation between the 0 and -3dB levels could be as large as 0.21°. This error is doubled because the TO and FRO beams tilt in opposite directions. A more reasonable value of 0.02 degree/dB would yield an error of just over 0.1°, which corresponds to the observed residual error at angles far from boresight.

It is recommended that the effect of the skew of the TO and FRO beams on guidance angle accuracy, and its relationship to the residual error, be studied by Transport Canada with data collected at DFL.

g) The accuracy and stability of the 2 microsecond clock used by the digitizer, and quantization errors introduced by the conversion process.

The same arguments used in c) above apply here as well. Again, the expected drifts in timing are smaller than allowed tolerances by orders of magnitude, as shown above.

In order to study the effects of short-term instabilities and non-linearities of the hardware on the guidance angle accuracy, a statistical analysis was suggested. There are two alternate sources of signals; one is the IFR Generator, the other one is the GANS.

The guidance angle accuracy tests were divided into two parts, one using the GANS and the other using the IFR generator as the signal source. In each case, a tape was generated for two angles, for each of the four functions (AZ, BAZ, HAZ and EL). The angles chosen were 2.5 and 8.0 degrees. The beam width was set at 2 degrees, and the sidelobe level (static) at -20 dB (in the case of the GANS). An archive and 16 frames were recorded on tape for each of the functions. This tape was supplied to Transport Canada, enabling them to perform an independent

analysis of the generated waveforms.

In the first part, using the GANS as the signal source, data were recorded on tape in order to allow statistical analysis to be performed to quantify the system noise errors. For this purpose, it is immaterial which function is used, or what angle is chosen, provided that the errors generated are random and the magnitude of the random error does not depend on the time within the scan. This is a very reasonable assumption to make for the MLS Signal Analyzer.

The GANS was used to generate a 2.5 degree beam for the azimuth function. This was recorded on tape, along with the archive. The process was repeated five times, giving a total of 80 scans (or frames) on tape. The process was repeated for 8.0 degrees, for the AZ, BAZ, HAZ, and EL functions. This gave a total of 640 frames. The program GANSACC, which did the statistical analysis, was run on that tape. In this, the first scan was used as a baseline, against which all other scans were compared. The root mean square deviation of each scan with respect to the first is a measure of the noise in the system. In addition, the mean angle, and the standard deviation of the measured angle were both printed. The mean is the best estimate of the angle from the available data. This would reveal any offset or bias (systematic error) in the measured value. The probable error was estimated assuming that the random errors were normally distributed. The probable error (PE) is defined as that value for which there is a 50% chance that the measurement will be between the values X - PE and X + PE, where X is the expected value. For a normal error distribution, the probable error is given by 0.674 σ. Thus, this analysis gives us a measure of both systematic and random errors.

During the measurement, the following parameters were obtained:

Initial : beam angle
asymmetry value

Final : mean beam angle
standard deviation of the beam angle
mean asymmetry value
standard deviation of the asymmetry.

The measured angle, which is the mean of all the angle measurements ± 0.674 σ (i.e the probable error) was recorded.

In the second part of the guidance angle accuracy test, a frame was chosen from the tape supplied earlier to Transport Canada in which the source was the IFR generator. The frame chosen for each angle and function was played back into the GANS, and thus repeatedly used as the signal. As before, 80 frames (5 sets of 16) were stored on tape, and analyzed using the program GANSACC. As before, the measured angle was recorded. It was found that the measured angle was close to that obtained from the statistical analysis. The agreement was always within the

specified error bound of 0.004 degrees. In only one case, for the IFR generator, was the angle found using the statistical analysis outside the actual measured value ± the probable error. This could mean either that the probable error was underestimated, or that there was an offset or bias error. However, even in this case, the disagreement was only 0.001 degrees.

5.4 Field Trials

In order to evaluate the performance of MLS antennas and transmitting systems, a test range has been designed by Transport Canada at the David Florida Laboratory (DFL). The system configuration for field trials on the MLS Signal Analyzer is shown in Figure 4. The antenna to be tested is mounted on a turntable, fitted with an optical encoder. This is installed on the roof of DFL. Beside the turntable is a hut, which houses the SA4116 positioner, and the encoder interface. Across open space is a tower on which is mounted the MLS receiving antenna. The configuration was carefully chosen to minimize multipath and reflection from adjacent structures to enable first article testing of MLS antennas under near-ideal conditions. At the foot of the tower is a hut, which houses the Signal Analyzer, the receiver and the SA2012A controller. The SA2012A controller was linked to the SA4116 positioner through IEEE-488 extenders, since

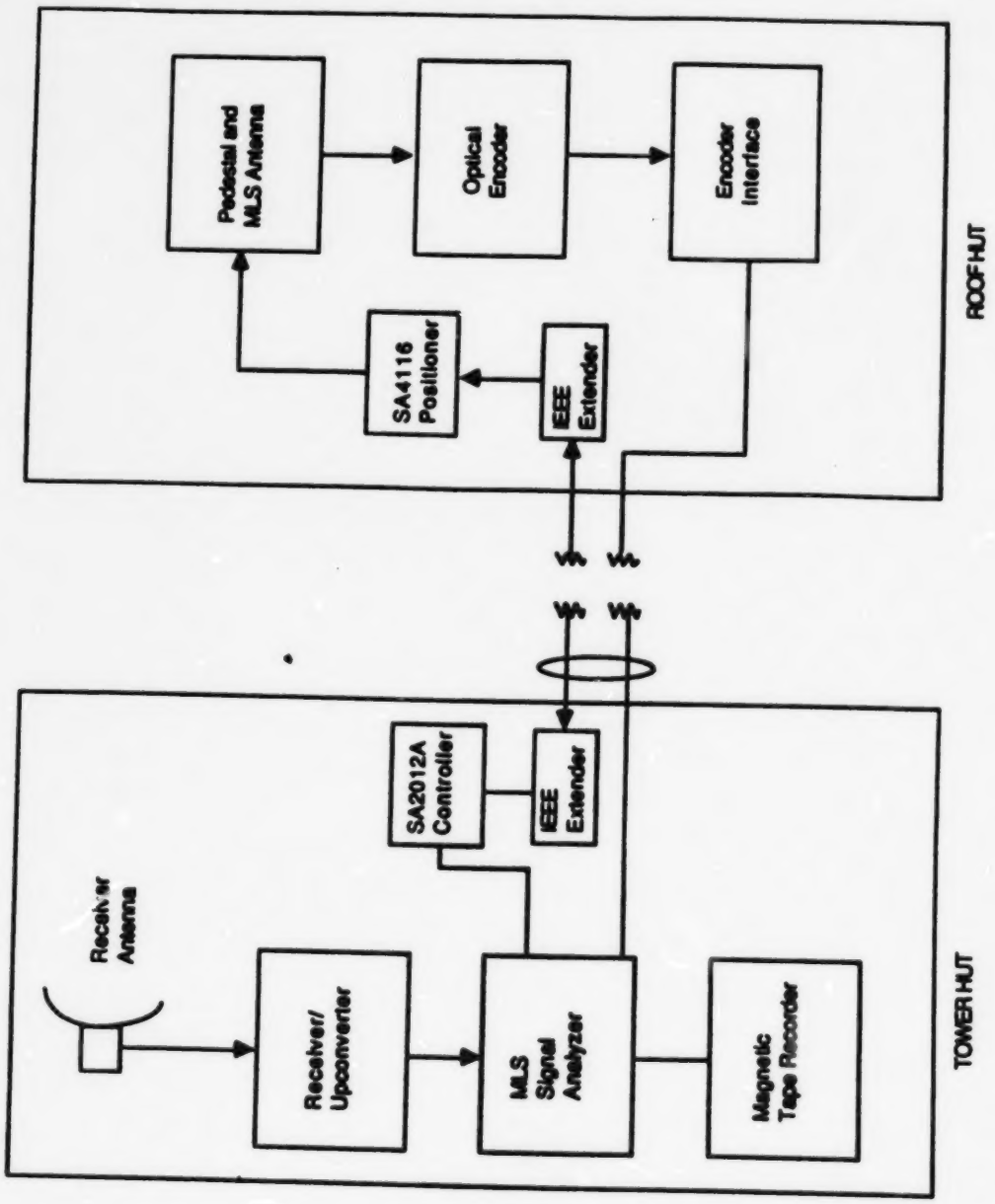

Figure 4 MLS Configuration at DFL

the IEEE-488 can only communicate over short distances. The encoder interface in the roof hut communicated with the Signal Analyzer through a 2400 baud RS232 serial link.

The facility at DFL was reserved by Transport Canada for field tests of the MLS Signal Analyzer for the beginning of September, 1988. At this time, the 16-bit optical encoder was mounted on the shaft of the turntable. After a couple of days of trials, it was discovered that the encoder readings sent to the Signal Analyzer were incorrect. The encoder was suspected, and the field trials were abandoned for the time.

In October 1988 the optical encoder was replaced by a 20-bit encoder. In the meantime, a fault was discovered in the RS232 link between the roof hut and the tower hut. DFL replaced the cables for this link. When CAL and Transport Canada returned to DFL to continue the field tests, the problems experienced earlier had been eliminated. This time, however, only an azimuth antenna was available for test. The tests planned for the elevation antenna were replaced by a longer data-collection period. As a result of the field tests, a large quantity of data was collected on tape. This was to be analyzed at a later date by Transport Canada.

However, attempts to complete the tests were unsuccessful. It was determined that the power level as seen by the receiver in the tower hut was too low to allow analysis. The RF connection from the receiver antenna was suspected. On November 15, 1988 it was discovered that the receiving antenna was misaligned, being set to horizontal rather than vertical polarization. This explained the low signal levels observed by the Signal Analyzer. This problem had remained unnoticed since spring. Tests were then conducted using the Hazeltine azimuth antenna.

The results of these tests indicated that the errors in the guidance angle were larger, and less predictable than when measured with the IFR800 signal generator, or with the GANS. The major difference between these measurements is that the geometry is important in the DFL field tests, but not for the laboratory tests. The conical scan correction is sensitive to the elevation angle. Therefore, it is essential to know the geometry of the range accurately. The phase centre offset corrections, in particular, are sensitive to even very small errors in the distances measured. For example, an error of 0.05° in the guidance angle corresponds to an error of just 30 cm on a 360 m range. An allowable angle error of 0.01° dictates that the distance between the phase centre and the receiver be within 6 cm. Similarly, the accuracy of the optical encoder needs to be verified. In spite of numerous requests that the encoder be calibrated, nothing was done to ensure that the encoder angles were accurate. It is strongly recommended that the angles as indicated by the encoder be calibrated using a theodolite, before any more data are collected at the range.

One task that CAL had been assigned was to monitor the serial line from the IEEE-488 Extender. It was believed that the

serial link was RS232, and hence could be monitored easily. However, it was discovered that the IEEE-488 does not use a standard serial communications protocol. Therefore, the idea of monitoring the serial link was abandoned. In the meantime, changes to the SA2012A controller software, and reduction in the noise on the serial line, had made monitoring the line unnecessary. The tests conducted at DFL are listed in Appendix A. The major finding was that guidance angles computed at DFL with a real antenna were less accurate than would have been expected. There are two components to these errors. The first is due to a variation in the angle as a function of the level at which it is computed. This contributes an error of about 0.1° at the largest azimuth angles. Another is an offset error varying from -1.2° at -50° azimuth to 1.4° at +50° azimuth. These errors could be related to the geometry of the DFL setup, which affects the conical scan and phase centre offset corrections, or to inaccuracies in the mounting of the optical encoder. These possibilities are discussed in greater detail in Section 5.5.

The field trials demonstrated that the Signal Analyzer is an effective tool for testing MLS equipment, and for collecting vast quantities of data on tape for future analysis.

5.5 Supplementary Investigations

During the measurements and tests described above, it was realized that there were a few items that needed to be studied further. These additional studies were expected to shed some light on the observed discrepancies in the angle measurements, and also to suggest methods by which the use of the Signal Analyzer could be made more efficient and accurate. Five additional investigations were identified as being the most important. The objectives and the work done for each of these tasks are described in the following sections.

5.5.1 Turntable Control

The first of the supplementary tasks was to investigate the possibility of speeding up the turntable control. During field tests earlier, it had been observed that the turntable movement was slow, thus making a full antenna test very time-consuming. One of the engineers on the project spent considerable time studying the control of the turntable using the SA2012A controller. The positioning system currently in use at DFL is shown in Figure 5 below.

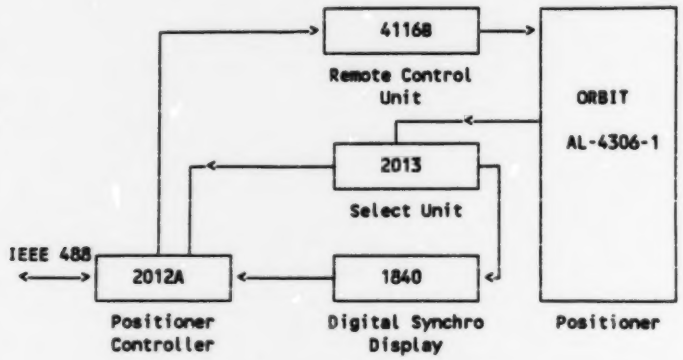

Figure 5 DFL Positioning System

The SA2012A controller operates in conjunction with the SA4116 positioner. There are two distinct modes of operation of the SA2012A controller. One of these is the POSITION mode, and the other is the RECORD mode. In the POSITION mode, the SA2012A drives the turntable to a specified position at a constant speed. This speed is chosen by operator control of a knob on the SA4116. There is no software control of the speed in the POSITION mode of operation. The selected speed must be chosen carefully by the operator. If it is set to drive the turntable too fast, the turntable can overshoot, and the system does not recover from this. In the RECORD mode, the speed of the turntable could be chosen to be fast initially, and slower as the required position is reached.

Since the POSITION mode does not provide remote speed control, it was thought originally that RECORD mode could be used to position the turntable. However, the RECORD mode does not allow turntable positioning with the same degree of accuracy as the POSITION mode. It was hoped that, by combining the two modes of operation, the turntable could be positioned both accurately and rapidly.

Although programmable scan speed is available in the 2012A controller, it was found that the SA4116 Positioner is an open-loop unit and does not support speed control from the remote controller. The SA4116, which is used to drive the antenna positioner, is designed for applications where speed regulation and precise positioning are not critical.

The usefulness of the RECORD mode in obtaining a faster positioning system is therefore limited. With the speed controlled by an operator, a fast positioning system can be obtained using the POSITION mode. The operator may select the speed setting, as well as a threshold. This threshold determines the accuracy of positioning. However, there is a trade-off between fast positioning and positioning accuracy. In the POSITION mode, the positioning accuracy is governed by the threshold setting. Intuitively, the threshold must be higher if the speed is increased. If the threshold is set too low for a

specific speed, the turntable will not be positioned properly. The risk of a runaway condition occurring is great under these circumstances. However, if the operator carefully chooses the speed and threshold, the efficiency and accuracy of positioning can both be improved, while at the same time avoiding the overshoot and runaway conditions. Figure 6 shows the minimum threshold setting that can be used for a various speed settings.

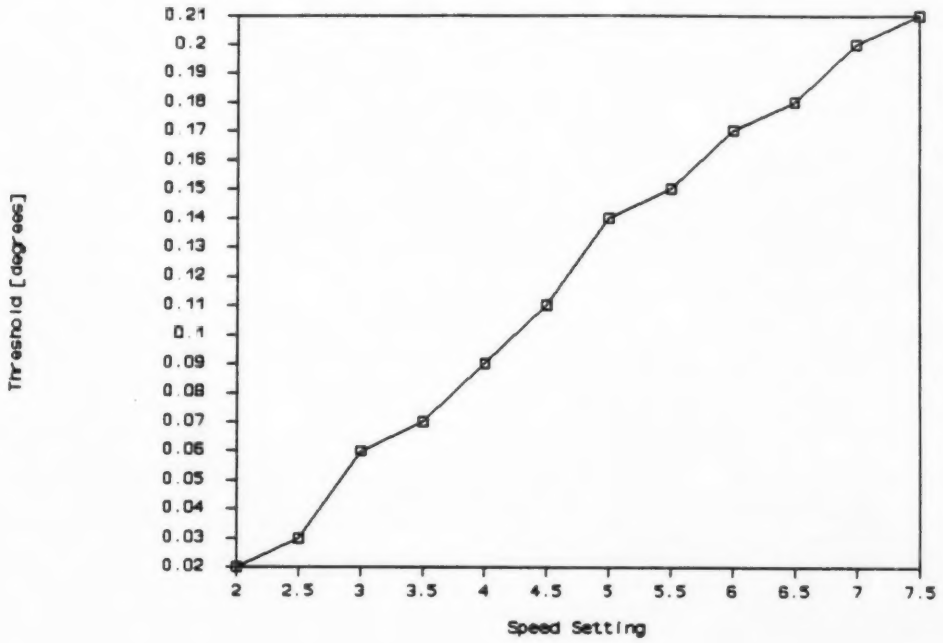

Figure 6 - Minimum Threshold vs the Speed Setting on the SA4116

In conclusion, it was found that, because of limitations of the current positioner (the Scientific Atlanta 4116), it is not possible to control the turntable speed remotely using the RECORD mode as originally proposed. Several alternatives were investigated. These included:

- the use of the POSITION mode with variable threshold;
- replacement of the existing SA4116 positioner with a Scientific Atlanta 4180 positioner; and

- the use of an advanced positioning system from ORBIT.

Without changing the existing hardware, it should be possible to introduce a variable threshold setting for turntable control in the POSITION mode. This may be included as a query in the operator interface, allowing the operator to choose the optimum speed and threshold combination for that test. The optimum threshold values for various speed settings, as illustrated in Figure 6, will be documented in the Operator's Manual for easy reference, if this option is chosen.

The second option would be to replace the SA4116 positioner with the Scientific Atlanta 418(positioner. The series 4180 positioner provides closed-loop speed-regulation signals and control signals based upon information derived from tachometers. A speed control range of greater than 100:1 is provided. Speed regulation is better than 1% of full speed over the entire range. The speed control can be programmed in the RECORD Mode. There are two speed ranges: the low speed range covers the range from 0.0 to 0.4% of the axis slew speed; the high speed range covers the range from 0.4% to 100% of the axis slew speed. Significant reduction in the time required for positioning the turntable can be achieved by using the high speed range for large angle movement. Accurate positioning is also possible by using the RECORD mode in conjunction with the POSITION mode. With this combination of modes, it is possible to speed up the positioning process while maintaining a positioning accuracy of 0.01°.

A third option, to permit better positioning accuracy and speed regulation, is to use an advanced positioning system from ORBIT. Figure 7 shows the ORBIT positioning system.

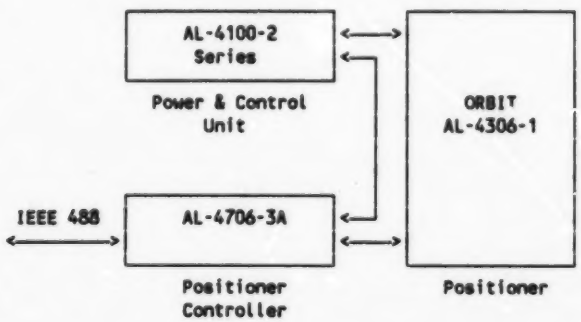

Figure 7 - Advanced Positioning System

The AL-4706-3A Advanced Positioner Controller and Programmer is a sophisticated high-precision unit designed to accept position data with accuracy of 0.0005° as measured by an Inductosyn encoder. This unit accepts tacho-feedback information directly from the positioner axes, subsequently using the data to close the motor-speed regulation loop. The speed control dynamic range is better than 200:1. Speed regulation accuracy is better than 1% of full speed over the entire range.

The Advanced Positioner Controller and Programmer interfaces directly with the series 4100-2 Power and Control Unit (PCU), to which it provides all signals necessary for axis selection and motor speed regulation and control. The PCUs are effective, high-performance drive systems which embody state-of-the-art control engineering technologies, including four-quadrant Pulse Width Modulation (PWM) techniques and sophisticated protective circuitry. In contrast to conventional SCR phase-angle controllers, these PCUs provide an inherently uniform drive to the motor, resulting in a smooth torque. Their broad bandwidth allows the motor to achieve the desired speed more quickly, and permits the control circuitry to provide superior acceleration/deceleration profiles.

The two basic modes of operation provided by the Advanced Positioner Controller and Programmer are the Positioning mode and the Recording mode, which are equivalent to the Position mode and Record mode respectively of the Scientific Atlanta 2012A programmable Positioner Controller. In contrast to the Position mode of the 2012A controller, programmable speed control is provided in the Positioning mode, as well as the Recording mode. By using the Positioning mode, it is possible to position the turntable with an ultra-high accuracy of 0.001°.

For the advanced positioning system, the turntable position is updated at a rate of 20KHz, compared to 100Hz for the existing system. With this high update rate, the positioning of the turntable can be speeded up without sacrificing the positioning accuracy.

For future range installations, CAL recommends the use of the ORBIT advanced positioning system described above.

5.5.2 Receiver Mistriggering

The second supplementary task was to investigate the cause of receiver mistriggering. The problem was first observed during the initial temperature stability tests. At the higher temperatures, the computed angles showed erratic anomalies that could not be explained at first. This did not happen at the lower temperatures, 20°C and below. It was suspected that the problem could be with the digitizer board. Plots were obtained of frames for which the angle was totally wrong. These plots revealed that the triggers were erratic, causing the whole frame to shift in time. An example of such a plot is shown in Figure 8. This is quite different from a proper frame, shown in Figure 9.

The algorithm used in the Signal Analyzer assumes that the trigger and the frame are related in a specific fashion depending on the function. Thus, the cause of the miscalculated angles was traced to the mistriggering. This phenomenon had not been observed with the other receivers used. CAL felt that the Bendix MLS receiver was the cause of the false triggers. On the other

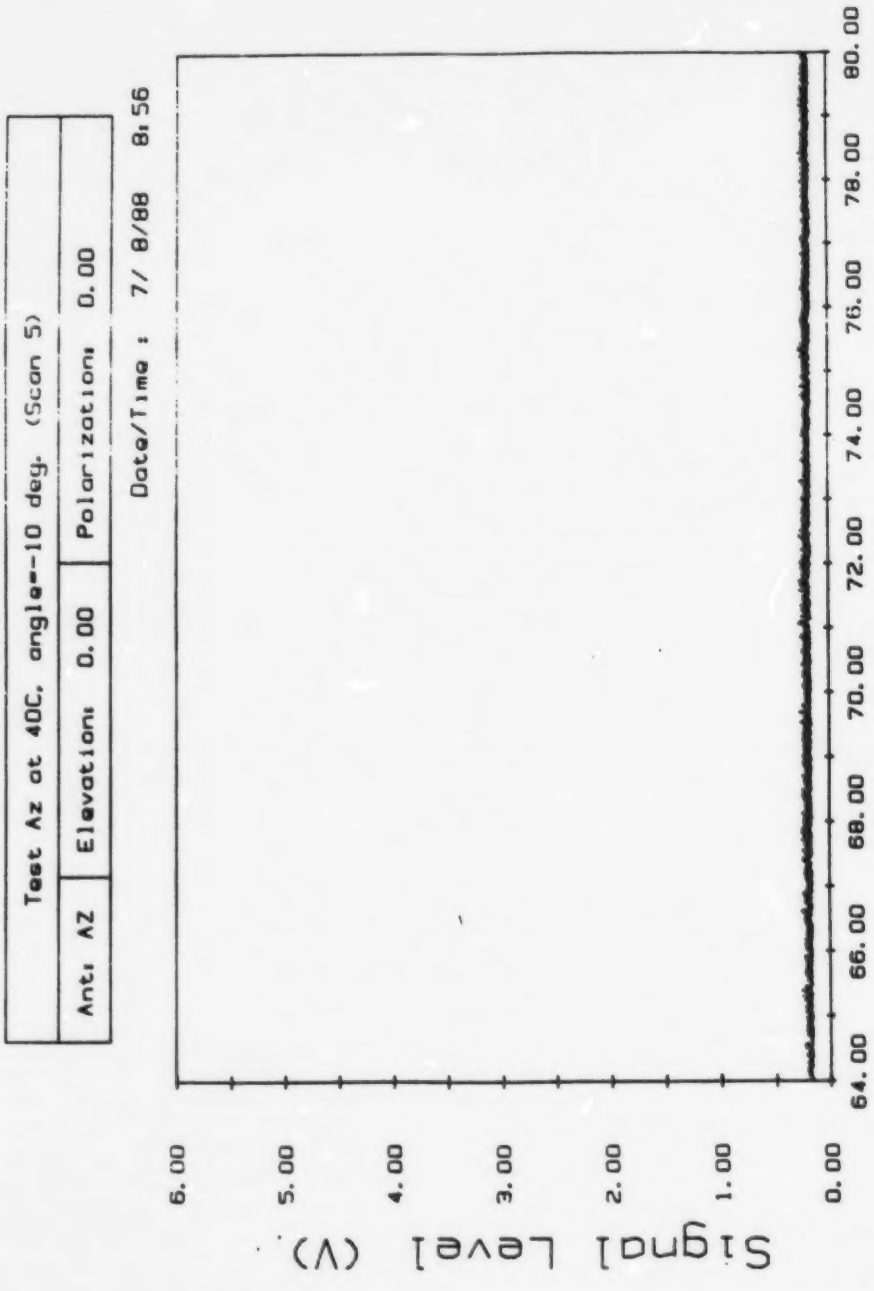

Figure 8 Example of a Mistriggered Frame

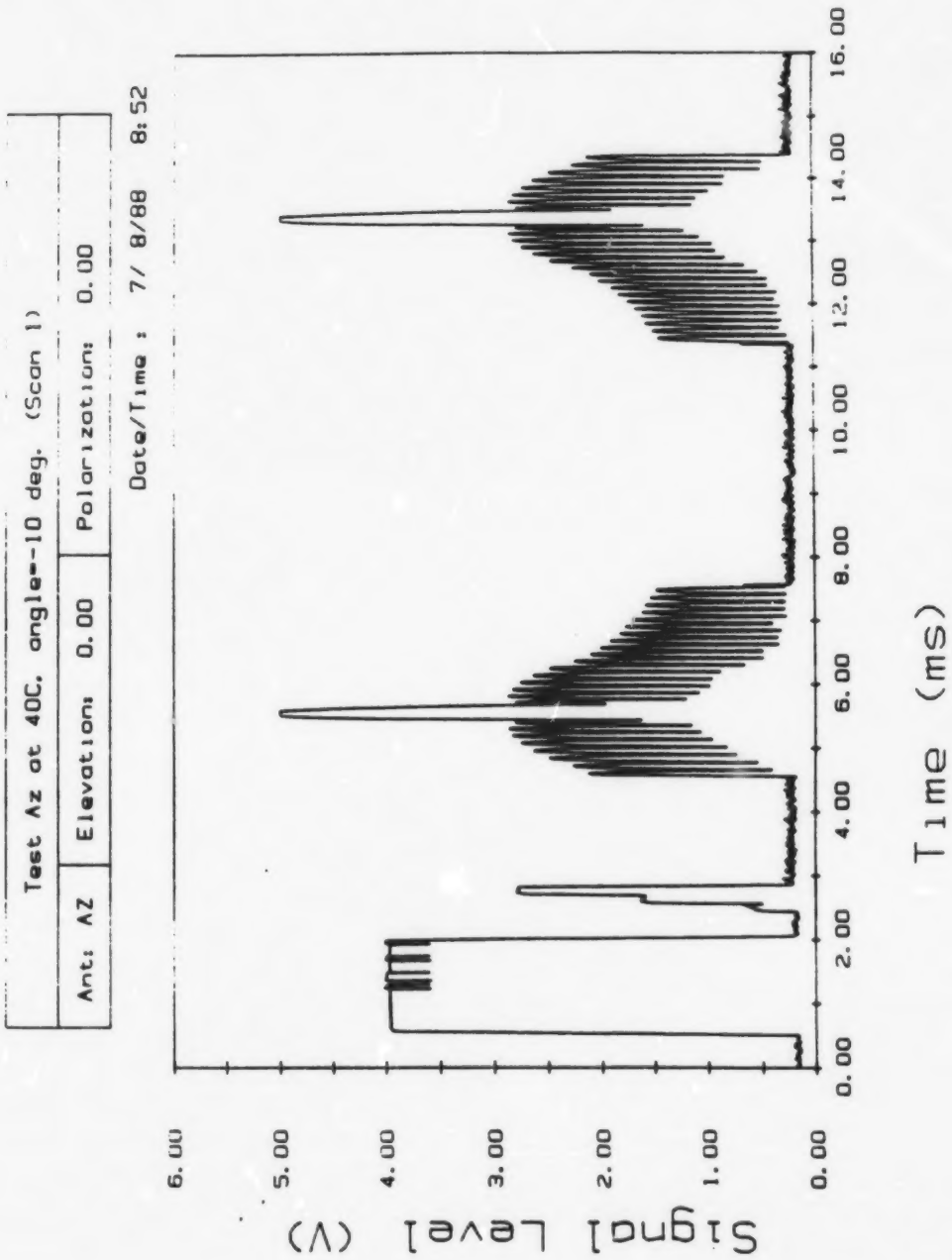

Figure 9 Example of a Properly Triggered Frame

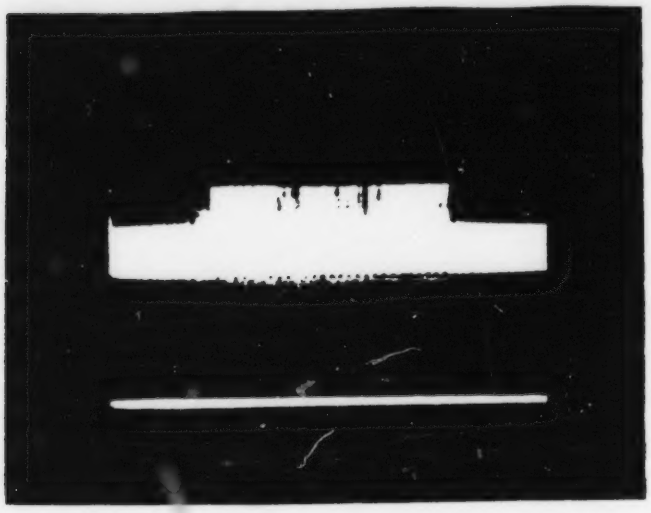

Figure 10 - Picture of the DPSK and Triggers from the First Receiver

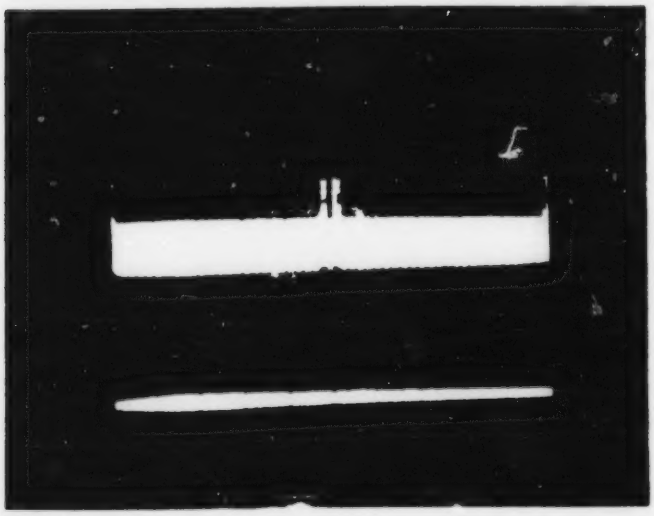

Figure 11 - Picture of the DPSK and Triggers from the Second Receiver

hand, it could also have been the digitizer misbehaving at the higher temperatures. In order to isolate the cause, another receiver was borrowed from Transport Canada, and both were tested. It was observed that no mistriggers were observed with the second receiver. Figures 10 and 11 show the DPSK and the triggers with the two receivers. As is evident from these photographs, the first receiver shows more DPSK noise between the triggers, as well as false triggers, while the second shows some noise but no false triggers. It can be concluded therefore that the first receiver was faulty. One can further conclude that only some Bendix ML201A receivers have this problem. Discussion of the problem with an engineer at Bendix has clarified the situation regarding the mechanisms by which the false triggers are generated. The DPSK looks for phase changes in the signal, signifying a change in preamble bit. Hence, all receivers will detect false triggers. Receiver manufacturers use different techniques to identify and reject false triggers.

There are essentially three different approaches. In the first, one can use the signal level to distinguish between false triggers occurring in noise and true triggers occurring during the preamble. This method assumes that the signal-to-noise ratio is large enough to set a threshold. The second technique is to disable the trigger generation for the duration of a frame. Thus, once a true trigger is detected, no false triggers can be generated during the frame. The third technique uses the fact that the noise bandwidth is higher than the signal bandwidth, which is approximately 15 kHz. Thus, noise above 15 kHz can be filtered out, before the DPSK is extracted. This last technique is used in the Bendix receivers. This method is suitable for use when the signal-to-noise ratio is not high, when a threshold would not be meaningful. The noise and filter characteristics will not be identical from receiver to receiver. Thus, we can have situations in which one receiver generates more random DPSK bits, resulting in false triggers, than another. Since the signal-to-noise ratio is guaranteed to be high for the Signal Analyzer, the first, second or a combination of the two methods can be used to ensure that false triggers are not generated. Another suggestion, made by the engineer at Bendix, was to not use the DPSK at all, but instead to look at the bits on the log video itself. Since each bit is 64 μsec long, it should be relatively trivial to recognize the transitions. Triggers generated using the log video are then guaranteed to be genuine, since the preamble occurs only at the beginning of a frame. The false trigger problem can occur with any receiver, and it is up to the digitizer to guard against them.

CAL recommends that the digitizer be modified to compare the level of the preamble when a trigger is generated, and to allow the generation of a trigger only when the preamble signal level is above a preset threshold. This technique was used by the Signal Analyzer software to detect false triggers, and proved to be fail-proof.

5.5.3 Behaviour of the IFR Generator

The third task in the supplementary study was to find out why the IFR generator waveforms looked suspiciously bad at the extreme angles, especially negative. The anomalies included large asymmetries and distortion in the shape of the clearance pulse. The main beams also looked distorted at the scan limits. These appeared to be due to the fact that the beam was too close to the Out-of-Coverage Indication (OCI) pulse. A number of phone calls were made to the manufacturers of the IFR800. The staff engineer ran bench tests while on the phone. The results, using their IFR800 showed few anomalies. The trouble with the IFR800s owned by Transport Canada were finally traced to the fact that these have not been updated with the current software. CAL recommends that both the IFR800s owned by Transport Canada be sent to IFR for engineering changes, and recalibration. Both the manufacturer and CAL are confident that this will remove the anomalies observed with the IFR800.

5.5.4 Beam Skewing at Large Angles

As had been mentioned earlier (Section 5.3), it had been observed that the TO and FRO beams tilt inwards. The effect is most noticeable at large angles. The fourth supplementary task was to investigate the effects of beam skewing, and to recommend whether or not modifications should be made to reduce or eliminate these errors. The phenomenon is present for the beams generated by the GANS and the MLS antennas. Both the IFR800 and Bendix generators merely superpose the TO and FRO beams on the sidelobes, at the correct separation for the required angle. Because of this artificial manner in which the IFR800 and the Bendix Signal generator produce the beam, such an effect should not be observed with these signal generators. This, apart from minor distortions, does seem to be the case. The data collected at the David Florida Laboratory (DFL) have been analyzed to study the effects of the tilt in the TO and FRO beams. The scan angles have been computed using the beam centres at the 1 dB through 10 dB levels. These were calculated for five azimuth angles from -50 to +50 degrees, applying only the conical scan correction, but excluding the phase centre offset corrections. The conical scan error is given by

$$\sin \theta' = \frac{\sin \theta}{\cos \phi} \qquad (1)$$

where θ' is the true guidance angle; θ is that measured; and ϕ is the elevation angle. Equation (1) above is valid at large distances from the MLS antenna, where the phase centre offsets are negligible. The errors introduced by the conical scan are shown in Figure 12, for various elevation angles. The sensitivity of these errors to small changes in the elevation angle is shown in Figure 13.

Figures 14 through 18 show the results obtained. It is observed from these graphs that the uncertainty in the angle, or spread in the error, is about 0.05 degrees at -50, 0.04 at -30; 0.02 at 0; 0.04 at 30; and 0.09 at +50 degrees. These values

give the spread in the data at different levels. The curves for the IFR800 are very flat, as would be expected if there were no tilt at all. The GANS results show the tilt as expected. The most surprising results are for the actual antenna, where the curves show erratic jumps, indicating that the approach of performing a linear regression may not be optimal. The erratic behaviour seems to suggest that the DFL range may be subject to some multipath or other effects. Apart from these peculiarities, larger errors are evident. For instance, at -50 degree azimuth, a correction of -1.2° has been applied to bring the angles closer to the nominal value.

There are two effects involved in these results. The first is the variation in angle from level to level. This is caused solely by the tilt in the TO and FRO beams. The second effect is the offset. An offset error can result from a number of causes. Firstly, the corrections for the conical scan and the phase centre offset may not be implemented correctly. This possibility is rather remote, since both Transport Canada and CAL have studied the algorithm and its implementation very carefully. However, even though the algorithms may be correct, the input parameters may not have been. It is clear from Figure 13, which shows the effect of conical scan alone, that the error is sensitive to the elevation angle. Any error in this could cause large errors in the computed angle. The same is true of the phase centre offset correction. Because these parameters affect the final result so critically, CAL recommends that in future field installations, all the geometrical parameters be carefully measured. Thirdly, the offset error could be due to errors in the optical encoder. Although this is a very accurate instrument, any slop in the mounting can cause large errors in the angle measured. In order to reduce all sources of offset errors, CAL recommends that the optical encoder readings be calibrated using a theodolite, and checked each time the encoder is moved. The graphs of Figures 14 through 18 show that, once all sources of offset errors are removed, an uncertainty of about 0.1 degree still exists. This is the error due to the tilt of the TO and FRO beams. Further, this error could vary from antenna to antenna, depending on the algorithm used for beam steering.

In summary, the single largest contribution to the guidance angle inaccuracy arises from the conical scan. This can be corrected in operational receivers using the formula given in equation in equation (1), using the measured azimuth and elevation angles. It is particularly important to do this for curved approaches. The residual error is then of the order of 0.1 degree, which can be removed for calibrated antennas. As the aircraft approaches the runway, the phase centre offset corrections become more important, but at the same time the need for extreme accuracy diminishes.

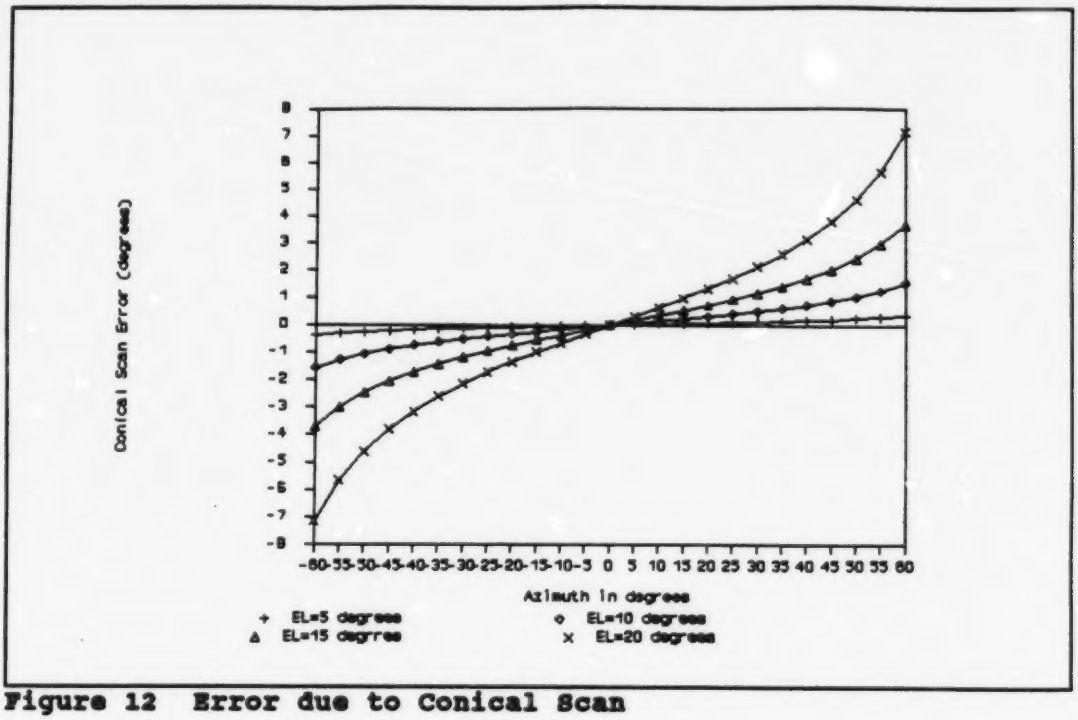

Figure 12 Error due to Conical Scan

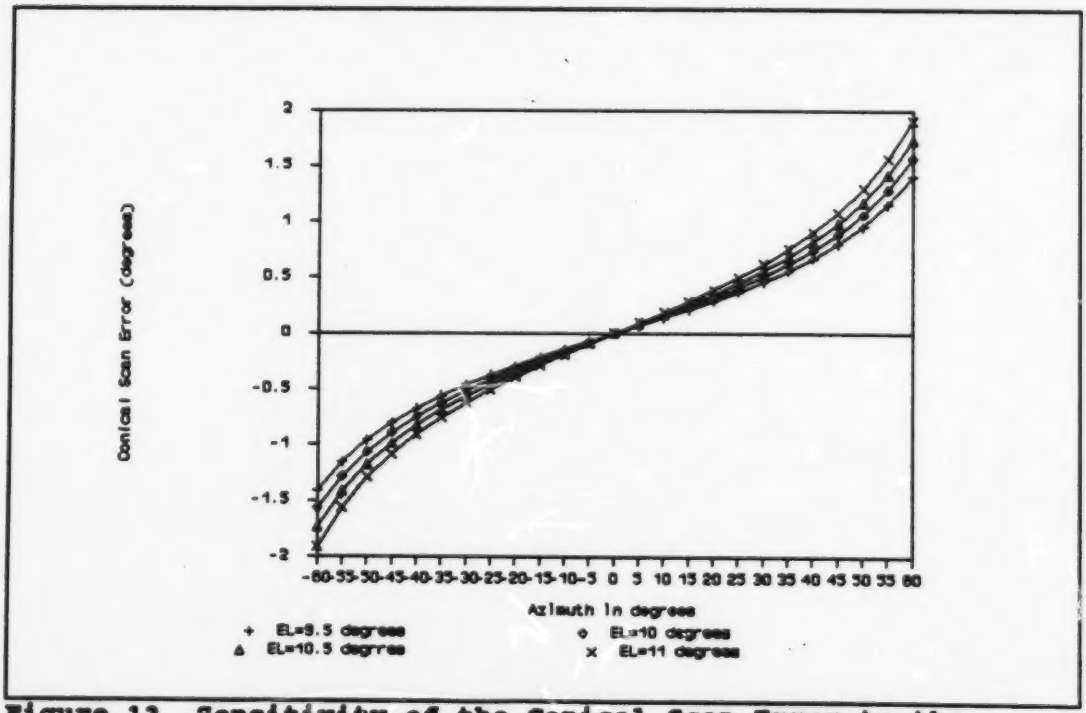

Figure 13 Sensitivity of the Conical Scan Error to the Elevation Angle.

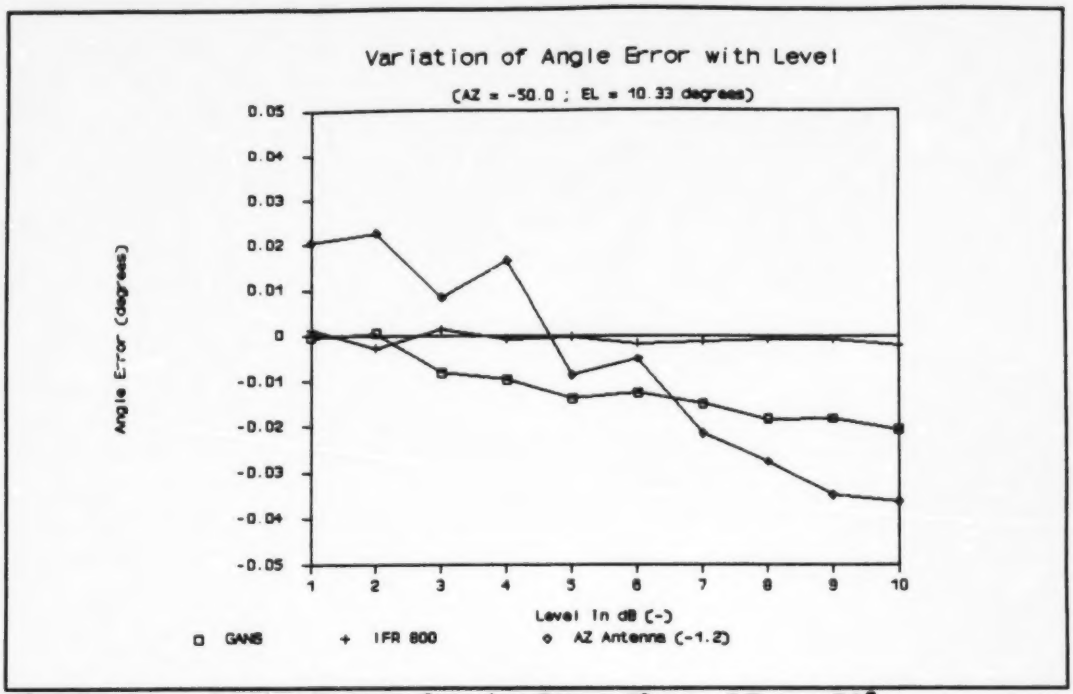

Figure 14 - Angle Error due to Beam Skew, AZ = -50°

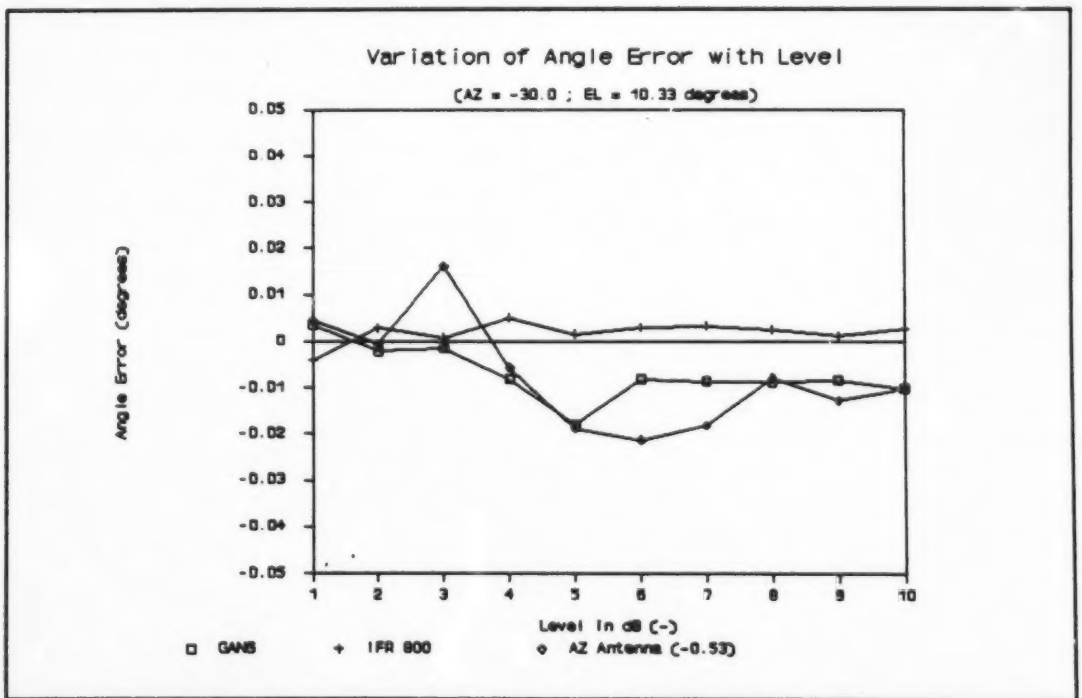

Figure 15 - Angle Error due to Beam Skew, AZ = -30°

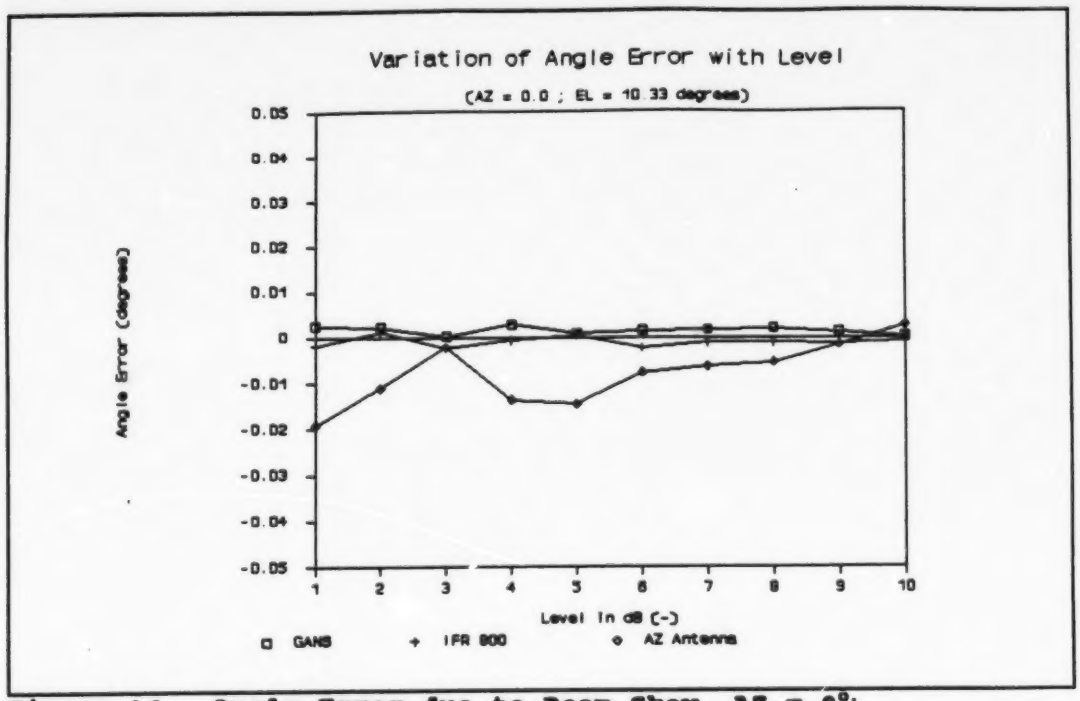

Figure 16 - Angle Error due to Beam Skew, AZ = 0°.

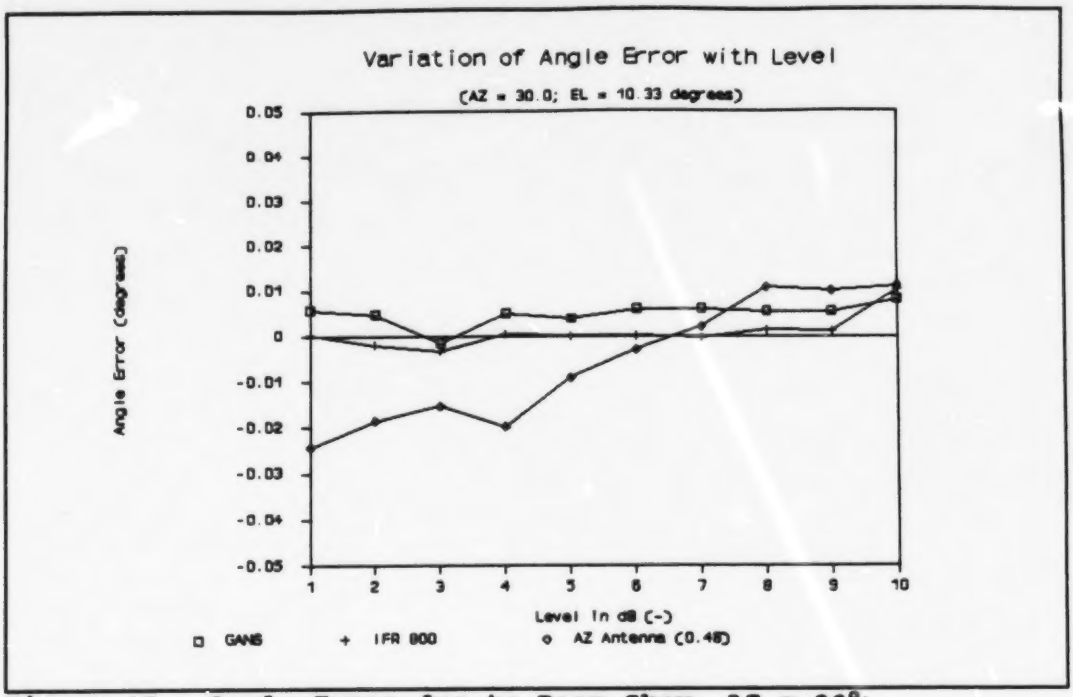

Figure 17 - Angle Error due to Beam Skew, AZ = 30°.

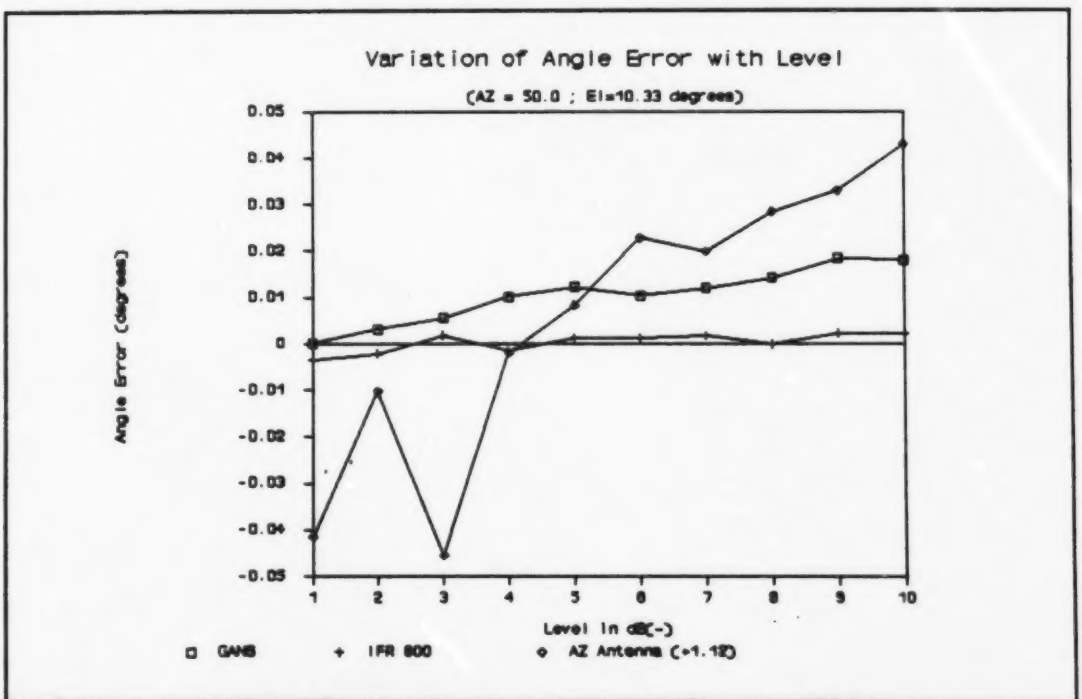

Figure 18 - Angle Error due to Beam Skew, AZ = 50°.

5.5.5 Errors at Negative Elevation Angles

The final supplementary task was to estimate the effort required to study the cause of the large errors at elevation angles of -0.5 degrees or lower. The largest errors were observed for the IFR800. It was verified by bench tests that the latest versions of the IFR800 could go to angles as low as -1.0 degrees. The GANS also produces little error at this angle. The reason the system cannot go below -1 degree is that the main beam approaches the OCI pulse too closely. This problem cannot be remedied, since the OCI pulse cannot be turned off in the IFR800. Thus, the limit to the angle measurement seems to be -1 degree. It is recommended that the IFR800 units at Transport Canada be upgraded to the latest version of the software. CAL feels that no further improvements can be made, and that the limit of -1 degree should be accepted as a system limitation.

6. CONCLUSIONS AND RECOMMENDATIONS

Based on the experience of CAL and Transport Canada with the Signal Analyzer, an accurate, versatile and well-characterized test system has now been developed and proven. The Signal Analyzer was found to meet the test criteria drawn up by CAL and approved by Transport Canada, in most cases well within the limits specified. In addition, the temperature characteristics of the Signal Analyzer have been measured for the particular MLS receiver (Bendix ML201A receiver serial number 1026) incorporated in the system. However, the present system is more of a research tool than a rugged equipment for field use. This will limit its functionality in the MLS environment. CAL believes that further modifications should now be considered in order to produce a lighter, more rugged version of the Signal Analyzer and to further increase its functionality. CAL's recommendations are divided into three categories, namely:

- Operational, relating to procedures for data collection, and range calibration
- Functional, relating to some cost-effective enhancements to the current system, and
- Packaging of the next generation Signal Analyzer.

<u>Operations</u>

For use as a range tool, the current Signal Analyzer appears to be quite satisfactory apart from being rather bulky. The accuaracy requirements were met in all test situations not using the MLS antenna. However, with the actual antenna, the results obtained by the Signal Analyzer did not agree with the encoder readings. It was later recognized that the encoder was not calibrated, and moreover, was removed and reinstalled each day with minimal checks. In all future measurements, CAL recommends the calibration of the encoder readings for at least four angles. These could consist of one small angle (near boresight) and one

large angle (say, 40°) on either side of boresight. The calibration may be done using a theodolite and fixed reference points. It is also recommended that a non-removable, weather-proof optical encoder be used, thus avoiding the daily removal and re-installation of the encoder. In addition, it is well known that the phase centre of the antenna is not the same as the physical centre of the antenna. It is recommended that Transport Canada obtain the location of the phase centre as measured by the manufacturer. Additional information that could prove useful is the movement of the phase centre as the antenna is tilted.

Functionality

Although the current Signal Analyzer is a useful tool, some additional functions could be added to make the system easier to use, and to provide some information that is currently not available. Some of the functions that could be easily incorporated are:

1. Analysis of the beam shape. The shape of the beam may be characterized by the difference between the -3dB and the -10dB beamwidths. A beam shape factor can be defined using these two measures. This can then be compared with ICAO specifications to see if the shape of the beam is acceptable. The baem shape could also be used to identify those cases where the main MLS beam is distorted by multipath or proximity to the edge of the scan.

2. Provision of a plot of the signal on the screen. The VT220 screen may be used as a graphics terminal to display the log video on the screen. This would enable the operator to preview log videos before obtaining a hardcopy of the plot. Furthermore, the plotting alogorithms could be improved to provide variable time bases, thus increasing the usefulness of the plots.

3. Statistical analysis on the angle output by the receiver, to provide PFE (Path Following Error), PFN (Path Following Noise), and CMN (Control Motion Noise). These last require the processing of all frames for a few seconds. This cannot be done if the Signal Analyzer processes the frames individually. However, the guidance angle data output by the receiver can be statistically processed to obtain the required quantities. This function could be an operator selectable option.

4. Timing analysis of the various bits in the DPSK signal. Such an analysis would provide additional tests of the antenna timing.

Packaging

New hardware, more compact and functional than the boards used in the Signal Analyzer, have become available since the time the Signal Analyzer was designed. It is worthwhile considering the use of some new hardware to decrease the bulk of the current

system. Possible hardware changes to the current system are:

1. The CPU now consists of 2 cards, one of which is the system controller. These can be reduced to one card. At the same time, new boards that use the faster 68020 microprocessor chip can be used. This will speed up the system, without forcing a software rewrite.

2. The receiver should be incorporated into the same box as the Signal Analyzer. The box should be one of reasonable size and weight.

3. The possibility of using other receivers (such as the Marconi, Pelorus etc.) should be investigated. A number of shortcomings were found in the Bendix Receiver which affected the performance of the Signal Analyzer, and which severely hampered the upgrade. Perhaps the greatest problem was that the lack of any uniformity in the performance of the Bendix receivers used. This may be due to the fact that they were being used for a purpose not intended by the manufacturer. Perhaps a receiver more suitable to the purposes of the Signal Analyzer could be found.

4. No matter which receiver is used, it is recommended that the digitizer board be modified to detect and ignore false triggers.

5. The ORBIT positioning system should be considered as a replacement for the SA2012A and the 4116 positioner. This alternative is superior to the current installation, and could provide faster and also more accurate positioning. At the same time. it is wise to consider the possibility os using the ORBIT encoder. Of course, the robustness of this encoder, as well as its resistance to condensation, should be verified. If this encoder is used, there will be no necessity for a separate encoder interface, and one can dispense with the 2400 baud serail line now being used. Instead, one would have a single communications line between the Signal Analyzer and the ORBIT subsystem.

6. The tape drive could be replaced by a more compact subsystem such as a high-density tape cartridge, a bubble memory, the new opto-mechanical disk drives (such as are being proposed for the NEXT computer), or the WORM (write once read many) disk systems. The alternatives need to be investigated.

7. The temperature dependence of the current system should be reduced by choosing new components for the upconverter/receiver subsystem. The objective should be to reduce the number of attenuators and other components, and to choose temperature-compensated components where possible. The temperature dependence of the receiver should also be investigated. By reducing the temperature sensitivity of the components, the operational temperature range of the Signal Analyzer would be increased, making it a more valuable tool.

Further Studies

In oder to gain a better understanding of the errors in guidance angle obtained using a real MLS antenna, it is recommended that Transport Canada study the effects of skew of the TO and FRO beams on the guidance angle accuracy, and its relationship to the residual error. This can be done using data collected at DFL. Additionally, it is recommended that the effects of errors in locating the phase centre on the guidance angle accuracy be studied.

Concluding Remarks

To summarize, the MLS Signal Analyzer is an instrument of great versatility and known accuracy. It can be used as an R&D instrument to test the performance of an antenna on a range, such as DFL, where the multipath returns are minimized. In addition to such testing, there is a real requirement to carry out extensive testing of MLS systems installed at airports. A test instrument for such a purpose can be fabricated easily, with just a few modifications to the present Signal Analyzer, and the addition of a suitable portable antenna mast.

GLOSSARY

A/D	Analog to Digital
AZ	Azimuth
BAZ	Back Azimuth
CAL	Canadian Astronautics Limited
CMN	Control Motion Noise
CPU	Central Processing Unit
dB	Decibel
D/A	Digital to Analog
DFL	David Florida Laboratory
DMA	Direct Memory Access
DPSK	Digital Phase Shift Key
DSLL	Dynamic Side Lobe Level
DSS	Department of Supply and Services
EL	Elevation
GANS	Guidance Angle Simulator
GFE	Government Furnished Equipment
HAZ	High Rate Azimuth
ICAO	International Civil Aviation Authority
ILS	Instrument Landing System
MLS	Microwave Landing System
OCI	Out-of-Coverage Indication
PCU	Power and Control Unit
PE	Probable Error
PFE	Path Following Error
PFN	Path Following Noise
PWM	Pulse Width Modulation
RF	Radio Frequency
ROM	Read Only Memory
SCR	Silicon Controlled Rectifier
TC	Transport Canada
TDC	Transportation Development Centre

APPENDIX A

1. Summary of Comprehensive Tests

The MLS Signal Analyzer was put through a series of tests, to verify that all changes made produced the required results, and to verify the operation of the unit. The tests were pre-approved by Transport Canada. The results were analyzed by Transport Canada before the tests were signed off, in many cases by doing a totally independent analysis on data taped during acceptance tests. Thus, the behaviour of the Signal Analyzer was scrutinized very carefully. Listed below are the tests that were conducted in the laboratory.

- Conical scan and phase centre offset corrections.
- Triggering on elevation frames.
- Collection of 16 consecutive frames.
- Power fail restart.
- Inversion of taped video by the GANS.
- The menu titles.
- The plot titles.
- The computation of the midscan error.
- The scan reversal for the elevation function.
- The accuracy of the beam generated by the GANS for each of the functions.
- The accuracy of the angle computation, using the IFR800 signal generator, as well as the GANS.
- The temperature dependence of the angle and power measurements.

All these tests produced results that were within the bounds specified, except for a couple of cases where the results were marginally out of tolerance. These were either at very low elevation angle with the IFR800 generator, or at the scan limits. It was agreed these were due to the IFR generator, or were statistically insignificant. In summary, the laboratory tests indicated that the Signal Analyzer was performing to the accuracy levels required.

When the comprehensive tests were successfully completed, field tests and a data collection session were organized.

2. Summary of Field Tests.

The Signal Analyzer was installed at the DFL range, where a Hazeltine azimuth antenna was mounted on a turntable. Here two sets of tests were conducted.

The first test was designed to verify that the encoder interface functioned properly, and that the turntable position was properly computed from the encoder output. However, as stated earlier, no independent check was performed on the accuracy of the optical encoder.

The second set of tests were designed to ensure that the Signal Analyzer correctly computed angles using the real MLS antenna. Much of the data from these tests were recorded on tape, for future analysis by Transport Canada. This analysis agreed with the results obtained using the Signal Analyzer. However, the accuracies obtained were not as good as was expected. A significant loss of accuracy can be attributed to the fact that the encoder was not calibrated, and that the geometry of the range was not measured accurately enough. These deficiencies reduce the confidence that can be placed on the field measurements. It is strongly recommended that, in future range trials, the positions of the phase centre and the receiver be carefully measured and documented. It may also be necessary to measure the electrical phase centre of the antenna, as well as the shift in this phase centre as a function of the tilt. CAL is confident that, if the range is properly characterized, the Signal Analyzer will accurately measure the angles generated by MLS equipment.

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